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RTCC REQUIREMENTS FOR MISSION D AND SUBSEQUENT MISSIONS: LOGIC FOR THE MISSION PLANNING TABLE

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PROJECT APOLLO

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By Ernest M. Fridge

SUMMARY AND INTRODUCTION

The mission planning table (MPT) and detailed maneuver table (DMT) displays present the planned orbital maneuvers and the lunar descent and ascent maneuvers to the Mission Operations Control Room (MOCR) and Staff Support Room (SSR). In developing the total display configuration, a basic objective has been to provide enough planning-aid displays to enable selection of the best maneuver plan, to transfer the selected plan to the MPT and DMT, and to adjust the plan only as required through manual and automatic updating operations. The role of the MPT processing in the chain of real-time computing is a finalizing one. Most of the planning-aid displays are employed to determine the best possible mission plan using impulsive maneuvers. Some processors requiring long-burn-time maneuvers, such as ascent, descent, and translunar injection (TLI), compute finite-thrust maneuvers in the planning-aid area. As the selected plan is transferred to the MPT, the effects of a finite thrusting are superimposed upon the impulsive maneuvers. The non-impulsive maneuvers which enter the MPT are merely integrated using the input targeting trajectory information.

The MPT defined in this paper will be used for Mission D and all subsequent missions. Certain changes will probably be implemented for each mission because of changing flight control requirements. However, this MPT, which forms the basis for MPT's for the later missions, differs considerably from the previously documented MPT (ref. 1). The major changes are:

1. The number of planning-aid processors than can enter maneuvers into the MPT has increased to seven. This number may vary in the future as new requirements arise.

2. Finite-thrust maneuvers can be entered into the MPT from some of the new planning-aid processors; the previous MPT could only receive impulsive maneuvers from planning-aid processors.

3. The MPT will no longer consider an iterable mission plan.

4. Ascent and descent maneuvers are included. The previous MPT only considered orbital maneuvers.

5. Trajectories around the earth, the moon, and between these two bodies are considered; thus, hyperbolic and parabolic trajectories are included. The previous MPT only considered near-earth elliptical trajectories.

6. The display formats are different; these will probably change for each mission as flight control requirements vary.

This report contains the logic for the MPT display which presents the selected mission plan. Since the DMT display is simply an extension of the MPT showing additional detailed information about individual maneuvers, the same logic package drives both displays.

The ground rules in this report contain the RTCC requirements for the MPT and DMT. The logic details for implementing these requirements indicate the manner in which they should be applied, and the RTCC should yield equivalent results although the program structure may be quite different. Discussions are also included of various routines (integrators, iterators, etc.) which, even though they are separate from the MPT, form an integral part of the MPT logic flow.

MPT LOGIC

The MPT is divided into two sections, MPT1 and MPT2, for programing convenience. MPT1 is a bookkeeping routine which organizes the MPT maneuvers according to the ground rules. MPT2 examines each MPT maneuver as often as required and calculates most of the display parameters.

MPT1

MPT1 is entered when any one of the following three options is desired.

1. Input a new set of maneuvers.

2. Delete a maneuver currently in the MPT.

3. Replace a maneuver currently in the MPT.

The MPT1 receives maneuvers from the planning-aid area, examines them for acceptance into the mission plan, rejects improper maneuvers, deletes and replaces maneuvers according to the ground rules, and finally, organizes the acceptable maneuvers according to time of execution into a mission plan.

Before MPT1 will perform any of the three options listed above, the option must pass the ground rules for a frozen maneuver - those to which the flight controller is committed and can no longer update.

The bookkeeping operations of MPT1 are conducted with the aid of three arrays (storage tables). Array ABC contains all of the input information, including the requested option and all the input parameters from the planning-aid area. Array ABCD stores all of the parameters required for MPT displays and updating. Since the MPT displays maneuvers in a time-ordered sequence, the maneuvers in ABCD are time-ordered and put into array ABCDE.

The following procedure guides the use of the arrays:

1. ABC is input to MPT1. This array will not contain any powered-flight parameters other than those necessary to initialize the powered-flight integrator (ignition time, targets, etc.). If ABC is rejected by violating the ground rules, no further MPT operations are done.

2. ABCD is reorganized and maneuvers are deleted according to the ground rules, if ABC passes the acceptance tests.

3. ABC is incorporated into ABCD.

4. The maneuvers in ABCD are time-ordered and put in ABCDE. New maneuvers which have not gone through MPT2 are flagged.

5. ABCDE is passed to MPT2 where new maneuvers are passed through the powered-flight integrator. Maneuvers in ABCDE which had previously been displayed are not integrated again at this time.

6. Parameters calculated in MPT2 are now stored in both ABCD and ABCDE where they are available for displays and future MPT updates.

MPT2

The MPT2 processor generates nearly all of the display parameters and is divided into two basic sections. One section updates the display as new maneuvers are entered, as old maneuvers are deleted, and as maneuvers are replaced. The other section, TUP, merely takes a trajectory update and reintegrates the entire mission contained in the MPT and DMT.

MPT2 is entered with the array ABCDE, which contains all of the parameters for controlling the MPT2 logic and all of the display parameters. If the route for adding, deleting, or replacing maneuvers is selected, then ABCDE has been updated by MPT1 just prior to entering MPT2. If the TUP route is selected, the ABCDE array following the last MPT update is used and MPT1 can be bypassed. In any case the arrays ABCD and ABCDE are common to both MPT1 and MPT2 and are kept updated with the latest trajectory information.

TUP Route of MPT2.- The TUP route automatically updates the MPT every time an orbit or vehicle-status update is made. TUP takes this latest information and starts with the first maneuver in ABCDE. This first maneuver is reintegrated using exactly the same conditions originally used (except as the flight controller might change according to the ground rules; i.e., new Lambert targets, etc.) and the maneuver is updated showing the effects of the trajectory or vehicle-status update. The coasting integrator then moves the state vector following the updated maneuver to the next maneuver in ABCDE. Each maneuver in ABCDE is updated in this maneuver; thus this array always contains only the latest trajectory information.

When a frozen maneuver which uses TLI, ascent, Lambert, or external-ΔV steering is to be updated, the powered-flight integrator is initialized so that guidance commands are generated from the specified vector (usually the onboard state vector) while the ephemeris is updated from the actual ground-computed vector.

No powered-flight iteration is performed in the TUP route.

Adding, deleting, and replacing maneuvers route of MPT2.- When the MPT is updated by adding, deleting, or replacing maneuvers, each new maneuver is integrated according to the ground rules, and the entire mission plan in the MPT is then taken through the TUP route as specified in the ground rules.

When a new maneuver is to be integrated, MPT2 must initialize the powered-flight integrator and iterator according to flight controller option and the ground rules. The guidance mode to be used for each new maneuver is entered as part of the initial input. The thrust model is established according to reference 2 and is also determined by the initial input. If the planning-aid processor which originated this new maneuver generated a finite trajectory, the maneuver goes straight to the powered-flight integrator and is integrated using the most current trajectory information. If the planning-aid processor has not used the recent trajectory in generating the maneuver, the display parameters on the MPT will differ from the planning-aid display. If the new maneuver was entered as an impulsive maneuver, the initial conditions for powered flight (attitudes and burn initiation time) are generated. When iteration is required, the controls are established by the ground rules.

When required, MPT2 calculates the Lambert target vector by the method outlined in the ground rules.

Powered-flight integration and iteration are now performed and the powered-flight parameters are output to the MPT for display and the calculation of other MPT display parameters. The powered-flight processing is discussed in more detail later in this note.

Additional display parameters.- Many display parameters are not burn parameters, but show vehicle characteristics or the results of a maneuver. The maneuver results are largely a function of the type of maneuver being performed. Many of these are found by coasting to the designated locations in the orbit following the finite burn and generating the desired display numbers.

Certain relative orbital parameters, such as phase, phase rate, and wedge angle after each maneuver, are displayed in the DMT. Calculation of these parameters requires a vector from the orbit of each vehicle at the specified time. The vector for the vehicle performing the current maneuver is taken from the orbit following burn termination. The vector for the passive vehicle is taken from the orbit at the completion of its last maneuver. These two vectors are propagated by the coasting integrator to the specified comparison times.

CSM and LM primary guidance system, external-ΔV targets must be computed for display purposes. This is the target vector and not the vector along which the vehicle will steer. The actual steering vector is calculated in the powered-flight process (integration and iteration when needed) and used to generate the powered-flight trajectory. MPT2 calculates the targeting vector so that the onboard logic will obtain the desired steering vector.

Display parameters which are peculiar to a particular planning-aid processor or to a particular guidance scheme are only generated when these conditions call for them.

Ground Rules

The entire processing of the MPT discussed above is controlled by the following ground rules.

Acceptance, rejection, and deletion of maneuvers.-

1. The MPT assumes no attempt will be made to enter any maneuvers prior to the last frozen maneuver for each vehicle. If this ground rule is violated, the MPT processor will reject the entering maneuvers.

2. The MPT will accept a set of maneuvers if each maneuver of this set for a given vehicle occurs after the time of the last frozen maneuver of the same vehicle. All maneuvers for this vehicle that were in the MPT prior to the entering of this new set are deleted if they occur after the time of the earliest maneuver in the new set for this vehicle.

3. When a maneuver for a particular vehicle is frozen, all maneuvers for that vehicle which occur prior to the maneuver being frozen will be automatically frozen. When a maneuver is unfrozen, all following maneuvers for that vehicle will be unfrozen.

4. The logic must be able to delete unfrozen maneuvers in the MPT. Maneuvers will be deleted by specifying the MPT code of the maneuver to be deleted. When a maneuver is deleted, all subsequent maneuvers for that vehicle are deleted.

5. Maneuvers will not be frozen automatically. All freezing is done manually by specifying the MPT code of the maneuver to be frozen. Maneuvers will be frozen only on direction from the flight-dynamics controller.

6. A maneuver for a given vehicle can be replaced in the MPT without changing the subsequent plan if it is input between the maneuvers which come immediately before and after the replaced maneuver.

Input from the planning-aid processors.-

1. Impulsive maneuvers will be sent to the MPT in one of the following two ways:

(a) For a general purpose maneuver processor (GPMP) or a rendezvous maneuver, the classical orbital elements (semimajor axis, eccentricity, inclination, argument of perigee, ascending node, and mean anomaly) describing the orbits before and after the impulsive maneuver will be input to the MPT along with the impulsive maneuver time.

(b) For any other impulsive maneuver, the state vectors (X, Y, Z, $\dot{X}$, $\dot{Y}$, and $\dot{Z}$) before and after the impulsive maneuver will be input to the MPT along with the impulsive maneuver time.

If the guidance flag for either case specifies Lambert steering, the control angle (true anomaly difference) between the impulsive point and the target point must be specified by the planning-aid processor. The target point will be determined by moving through this angle along the conic defined by the orbit after the impulsive maneuver. The guidance constant C is also entered by the planning-aid processor, but it can be updated during the mission.

Nominally, external-ΔV maneuvers will be centered about the impulsive maneuver point. Lambert-guided rendezvous maneuvers (CDH, CSI, TPI, MCC) will be started at the impulsive point. Other Lambert maneuvers will be centered about the impulsive maneuver point. These nominal settings can be overridden by flight controller request.

External-ΔV maneuvers which are part of the rendezvous sequence can be centered or started at the impulsive maneuver point. If they are begun at the impulsive point, the inertial thrust vector will be in the direction of the impulsive ΔV vector rotated through one-half of the predicted burn arc, as in reference 3.

2. Maneuvers can be directly input by the flight controller to the MPT. This option also includes the capability of inputting certain parameters for the purpose of confirming a maneuver which has already been performed. The details for direct input have been furnished by IBM and are given in table I. The options include the following:

(a) Input or confirm TLI maneuvers.

(b) Input inertial maneuvers defined in a specified coordinate system.

(c) Input Lambert-guided maneuvers in either an earth-centered or moon-centered inertial coordinate system.

3. For ascent maneuvers, the ignition state vector will be taken from the ephemeris at the input lift-off time. The remaining targeting will be generated in the planning-aid processor.

4. For descent maneuvers, the ignition state vector will be taken from the ephemeris at an input ignition time or from an ignition time calculated by the engine-on algorithm. This choice is determined by flight controller input.

5. For the TLI maneuver, the ignition state vector will be taken from the ephemeris at the specified ignition time. Flight controller input determines the option of whether to use the existing targets which were input from the planning-aid processor or whether to calculate them in the TLI guidance package used by the powered-flight integrator. The flight controller cannot transfer a hypersurface solution from the planning-aid area to the MPT.

6. For a return-to-earth maneuver (mission abort, TEMC, or TEI), the ignition state will be taken from the ephemeris at ignition time. Targets for the various guidance options are computed in the return-to-earth abort processor.

Iteration procedures.-

1. Only LOI and GPMP maneuvers will be iterated.

2. Nominally, LOI maneuvers will be iterated, and GPMP maneuvers will not be iterated. The nominal procedure can be overridden by flight controller input.

3. The dependent variables for LOI will be semimajor axis, eccentricity, angle between impulsive maneuver point and burnout lunar parking orbit pericynthion vector, wedge angle, and two angles replacing the inclination and right ascension of the desired orbit plane. For orbits whose eccentricity after the impulsive maneuver is less than some value to be determined, the angle between the impulsive point and burnout lunar parking orbit pericynthion vector is omitted.

4. The dependent variables for GPMP maneuvers will be semimajor axis, eccentricity, inclination, argument of perigee and ascending node. For orbits whose eccentricity after the impulsive maneuver is less than some value to be determined, the argument of perigee is omitted.

5. The independent variables for a Lambert-guided maneuver will be the guidance constant C, the ignition time, and the flight time from ignition to the target aim point.

6. The independent variables for an external-ΔV maneuver will be right ascension, declination, total ΔV, and thrust ignition time. Investigation continues as to the desirability of using right ascension and declination.

7. No iteration will be performed on a "short" maneuver. The criteria for determining a short maneuver are being decided; however, the test will be the same as used in the return-to-earth processor. A message will be output if iteration is prevented for this reason.

8. Two sets of tolerances, weights, and step sizes will be stored in the MPT. One will be used for LOI; the other for GPMP maneuvers. The weights will be a function of the tolerances and will be determined by

$$\text{weight}(J) = \frac{\text{constant}}{\text{tolerance}^2(J)}.$$

where J is a subscript representing the various dependent variables.

Trajectory update (TUP) logic.-

1. When a trajectory update is required, the entire mission plan in the MPT is automatically integrated again, and the displays updated.

2. A trajectory update is automatically called any time maneuvers are added, deleted, or replaced in the MPT.

3. For a frozen Lambert-guided maneuver, guidance commands will be generated from the specified state vector (usually the onboard state vector), while navigation will be performed on the ephemeris vector.

4. For a frozen TLI maneuver targeted by the hypersurface or the TLI processor, the targets will be frozen. Guidance commands will be generated from the specified state vector (usually the onboard state vector), while navigation will be performed on the ephemeris vector. For an unfrozen TLI maneuver targeted by the TLI processor, the targets will be frozen. Guidance commands will be generated from the ephemeris vector, and navigation will be performed on the ephemeris vector. For an unfrozen TLI maneuver targeted by the hypersurface, the targets will be changed by the TUP. Guidance commands will be generated from the ephemeris vector, and navigation will be performed on the ephemeris vector.

The TLI processor solutions with the exception of the hypersurface solutions can be transferred to the MPT. The hypersurface solutions may be obtained in the MPT by an unfrozen hypersurface-targeted maneuver with the appropriate ephemeris vector.

5. For all external-ΔV maneuvers guided by a primary system, the target ΔV components will never change. These target components are the input expected by the onboard program and not the actual thrust vector. For an unfrozen maneuver, the inertial thrust direction may change due to trajectory updating. If the maneuver is frozen, this inertial thrust direction will also remain fixed.

6. For an AGS, external-ΔV maneuver in which the AGS will perform the guidance, the target ΔV components will never change. Thus for an unfrozen maneuver, the inertial thrust direction may change because of trajectory updating. If the maneuver is frozen, this inertial thrust direction will also remain fixed. A CSM update will not update LM external ΔV. The LM will have to be updated operationally.

7. For an AGS, external-ΔV maneuver in which the AGS is a backup to the primary system, the target ΔV components will change as required. For an unfrozen maneuver, they will change so that they will always be the actual AGS target components which would yield the actual inertial thrust direction. For a frozen maneuver, the AGS target ΔV components remain fixed.

8. For a frozen ascent maneuver, guidance commands will be generated from the specified vector (usually the onboard state vector), while navigation will be performed on the ephemeris vector.

9. The descent maneuver will always generate guidance commands from the ephemeris vector. If the maneuver is unfrozen, ignition time can be computed in the engine-on algorithm or specified by the flight controller. If the maneuver is frozen, the ignition time is held fixed at its latest value prior to freezing.

POWERED-FLIGHT PROCESSING

With the aid of the powered-flight integrator and iterator, MPT2 generates most of the required powered-flight parameters. (Certain initializing parameters such as ignition time, targets, etc. can be input to the MPT.) The capability exists to superimpose finite trajectories on impulsive maneuvers and iterate until satisfactory conditions are met; to integrate two trajectories simultaneously applying a command acceleration vector to both; and to generate the initial conditions required to start the powered-flight processing.

Generation of Initial Conditions

When a powered-flight trajectory must be superimposed on an impulsive maneuver, the starting conditions such as attitudes, ΔV, and main engine ignition time must be determined. This is done by calculating the velocity vector both before and after the impulsive maneuver. These can be calculated from the orbital elements or determined directly from the input state vectors. The initial conditions are then computed in the following manner:

$$\Delta T_{BI} = \frac{\displaystyle\sum_{i=0}^{n} \frac{T_i}{\dot{w}} \left\{ t_{i+1} - t_i + \frac{(w_i + \dot{w}_i t_i)}{\dot{w}_i} \ln\left[\frac{w_i - \dot{w}_i (t_{i+1} - t_i)}{w_i}\right] \right\}}{\displaystyle\sum_{i=0}^{n} \frac{T_i}{\dot{w}_i} \ln\left[\frac{w_i - \dot{w}_i (t_{i+1} - t_i)}{w_i}\right]}$$

$$Tig = Timp - \Delta T_{BI}$$

where

ΔT_{BI}	Δt between the impulsive maneuver point and the thrust initiation point
i	index representing the various thrust phase (see ref. 2)
T	thrust level
w	vehicle weight
$\dot{w}$	propellant weight flow
t	time since thrust initiation
T_{imp}	impulsive maneuver time
Tig	thrust initiation time

If the maneuver is a Lambert-guided maneuver, the guidance constant C is input as specified in the ground rules. TF (the conic flight time from the impulsive maneuver point to the target point) is calculated in subroutine TIME-THETA. The attitude and burn times are part of the guidance calculations.

If the maneuver does not use Lambert guidance, the following variables are needed:

$$\Delta\overline{V}_I = \overline{V}_F - \overline{V}_o$$

$$\text{Declination} = \sin^{-1}\left([\text{unit}(\Delta\overline{V}_I)] \cdot \overline{u}_z\right)$$

$$\text{Right ascension} = \tan^{-1}\left[\frac{\Delta V_I \text{ (Y component)}}{\Delta V_I \text{ (X component)}}\right]$$

where

$\overline{u}_z$	unit vector along polar axis of the reference body
$\overline{V}_o$, $\overline{V}_F$	inertial velocity vectors before and after the impulsive maneuver

$\Delta\overline{V}_I$ inertial ΔV vector at the impulsive point

Powered-Flight Integrator

After the thrust initiation conditions have been established, either by input or by the method outlined in the preceding paragraph, the powered-flight integrator is called to generate the trajectory. This routine must have the following capabilities:

1. It can call the coasting integrator to move to the desired starting vector.

2. It can generate the proper gravity acceleration component needed for any phase of the mission (earth, lunar, and between the earth and moon).

3. It can produce trajectories using the thrust profiles for the specified engines.

4. It can integrate two trajectories simultaneously so that guidance commands can be generated from one trajectory and the resulting thrust acceleration can be applied to both trajectories. This double integration will be used primarily for integrating frozen maneuvers so that guidance commands can be generated from the onboard state vector and applied to the current ephemeris vector.

5. It can generate trajectories using the following guidance options:

(a) Lambert - This scheme will target to the input offset aim vector.

(b) Primary systems external ΔV - The input target vector will be rotated by this guidance package as indicated in reference 3.

(c) TLI.

(d) Ascent.

(e) Descent - This includes the option to use the engine-on algorithm.

(f) Secondary control system - Thrust vector is inertial throughout burn.

(g) Manual - Body axis is held inertial throughout burn.

(h) AGS external ΔV.

Powered-Flight Iterator

The iteration method is the same as a class I in the generalized forward iterator. It can be used only to superimpose an acceptable finite trajectory on the input impulsive maneuver. An acceptable trajectory is one in which the orbital elements after the finite burn match within specified tolerances the desired orbital elements produced by the impulsive maneuver. If convergence to the desired elements is not possible, the iteration process will find the best trajectory. This best trajectory is the one in which the sum of the weighted squares of the errors is a minimum.

The choice of iteration variables is set in MPT2 according to the ground rules. The dependent variables are always defined at the time of the impulsive maneuver. This is accomplished by entering the coasting integrator with the orbit following the finite burn and coasting back to the impulsive point. The GPMP dependent variables will be the specified orbital elements and can be taken directly from the powered-flight integrator. The LOI dependent variables - a, e, n, θ_1, θ_2, θ - will be obtained in the following manner:

a — semimajor axis, which can be taken directly from the powered-flight integrator.

e — eccentricity, which can be taken directly from the powered-flight integrator.

n — angle between the impulsive maneuver point and the burnout lunar parking orbit pericynthion vector. There is an initialization procedure to determine if n will be between $\pm\pi$ or 0 to 2π. The initialization computation is made as follows.

$$\cos n_D = \overline{r}_I \cdot \overline{up}_D$$

$$\sin n_D = \text{sign}[(\overline{up}_D \times \overline{r}_I) \cdot \overline{u}] \left| \overline{up}_D \times \overline{r}_I \right|$$

$$n_D = \tan^{-1} \left[\frac{\sin n_D}{\cos n_D} \right]$$

where

$\overline{up}_D$ — unit vector to pericynthion of the impulsively defined lunar parking orbit

$\overline{r}_I$ unit vector along the radius vector of the impulsive maneuver

$\overline{u}$ unit vector along the desired angular momentum vector defined by the impulsive elements

n_D desired value of n

$\overline{up}$ unit vector to pericynthion of burnout lunar parking orbit

Then n is computed by the equations:

$$\cos n = \overline{r}_I \cdot \overline{up}$$

$$\sin n = \text{sign}[(\overline{up} \times \overline{r}_I) \cdot \overline{u}]\ [\ \overline{up} \times \overline{r}_I]$$

$$n = \tan^{-1}\left[\frac{\sin n}{\cos n}\right]$$

If n_D is in the second or third quadrant and n is negative then set

$$n = n + 2\pi$$

θ_1, θ_2 angles which correspond to inclination and right ascension

$$\theta_1 = \text{sign}\ [\overline{u}_{s/c} \cdot \overline{r}_i]\ \sin^{-1}\left\{ |\overline{u}_{s/c} \times [\text{unit}(\overline{u}_{s/c} - (\overline{u}_{s/c} \cdot \overline{r}_I)\ \overline{r}_I)]| \right\}$$

$$\theta_2 = \text{sign}\ [\overline{u}_{s/c} \cdot \overline{w}]\ \sin^{-1}\left\{ |\overline{u}_{s/c} \times [\text{unit}\ (\overline{u}_{s/c} - (\overline{u}_{s/c} \cdot \overline{w})\ \overline{w})]| \right\}$$

where

$\overline{r}_I$	unit vector along the radius vector of the impulsive maneuver
$\overline{V}_{LPO}$	desired impulsive velocity vector
$\overline{u}$	unit $[\overline{r}_I \times \overline{V}_{LPO}]$
$\overline{w}$	$\overline{u} \times \overline{r}_I$
$\overline{u}_{s/c}$	unit vector along the angular momentum vector defined at burnout

θ signed wedge angle defined by

$$\theta = \text{sign}\,[\overline{u}_{s/c} \cdot \overline{w}]\ \sin^{-1}\,[\,|\overline{u} \times \overline{u}_{s/c}|\,]$$

NOTE: Either θ or the combination of θ_1 and θ_2 will be used.

Auxiliary Subroutines

Certain general subroutines are called by the MPT. IBM already has most of these subroutines so the details of all but four are not included in this report. A list of the required subroutines and a brief description of each follows.

A coasting integrator is required to propagate the vehicles during the free-flight phases. This routine is also required by the powered-flight integrator to propagate the vehicle from the impulsive maneuver point to the point of maneuver initiation. This coasting integrator contains reference body tests and applies the correct gravitational model for any phase of the mission.

CONIC is a coasting integrator which uses only a two-body gravity model. It propagates along a conic section for any type of orbit.

Subroutine STAP utilizes the coasting integrator in an iteration process to locate the actual apogee and perigee of the orbit resulting from the maneuver.

GIMAG is a table look-up routine which determines the pitch and yaw trim gimbal angles for both vehicles as a function of vehicle weight. This subroutine includes the trim gimbal angle calculations for thrusting with either vehicle while in a docked configuration.

THETR calculates the phase angle between two vehicles at a given time.

SHORTM is a subroutine that examines each new maneuver to determine if its execution time is such that it can be classified as a short maneuver. The burn duration criteria are established and given in references 3 and 4 and vary with the different engines. Integrator controls will be set to prohibit steering for short maneuvers (other than DPS), and iteration will be prohibited. For the DPS, both steering and throttle level controls will be set. This processor will take into account the effects of either two- or four-jet ullage. The ullage duration for each main engine is fixed in the program.

TIME-THETA solves the transfer time required to cover a specified true anomaly increment using two-body motion. It solves the problem for any kind of orbit and is defined in reference 3.

LNDSIT yields the landing site radius vector based on the landing site latitude and longitude. The time of the landing site vector definition must be specified.

ATMR sets up a coordinate system corresponding to the preferred IMU alignment for thrusting.

ANGLE orients the vehicle body-axis system for the maneuver. Trim gimbal angles and the RCS thrust axes offset from the body axes are taken into consideration.

TANGLE calculates the pitch, roll, and yaw display parameters. The order of rotation and the reference coordinate systems are determined by input.

FDAI calculates the FDAI angles required for display.

TABLE I.- DIRECT INPUT MANEUVERS

(a) TLI direct input

M68, TABLE CODE, REPLACE CODE, OPPORTUNITY, THRESHOLD TIME,/inclination, longitude of descending node, eccentricity, $-\mu/a$, true anomaly of descending node, estimated true anomaly at cutoff/;

Table Code - CSM or LM depending on which ephemeris is to contain the TLI maneuver.

Replace Code - If it is desired that the TLI maneuver being input should replace an existing maneuver, the maneuver number should be input.

Opportunity - The opportunity for which the maneuver is to be computed.

Threshold Time - Threshold time (time of restart prep) at which the maneuver is to be performed.

/Target Parameters/ - If the target parameters are known for the desired opportunity and threshold time they may be specified.

TLI Direct Input Options
M68, TABLE, REPLACE, OPPORTUNITY;
M68, TABLE, REPLACE, OPPORTUNITY, THRESHOLD TIME;
M68, TABLE, REPLACE, OPPORTUNITY, THRESHOLD TIME,/TARGETS;/

(b) CSM/LM direct input

I. M40,/BURN PARAMETER OPTION, BURN PARAMETERS/;

BURN PARAMETERS OPTIONS - P1, P2, P3, P4, P5, P6
a) Burn Parameters for P1 - ΔV, $\Delta V_{\text{Indicator}}$, Δt

Example: M40,/P1, ΔV, $\Delta V_{\text{Indicator}}$, Δt/;

ΔV is the ΔV magnitude or ΔV along the X-body axis as specified by the $\Delta V_{\text{Indicator}}$.

ΔV Indicator - MAG (ΔV Magnitude)
DVC (ΔV along X-body axis - incl. ullage, no tailoff)
XBT (ΔV along X-body axis - incl. ullage and tailoff)

Δt - If ΔV option is not desired then ΔV, $\Delta V_{\text{Indicator}}$ are omitted and a Δt of the maneuver can be specified.

b) Burn Parameters for P2 - $\overline{\Delta V}$ vector in the command and display system, ΔV override, Δt override

Example: M40,/P2, $\dot{X}$, $\dot{Y}$, $\dot{Z}$, $\Delta V_{\text{Override}}$, $\Delta t_{\text{Override}}$/;

$\dot{X}$, $\dot{Y}$, $\dot{Z}$, - $\overline{\Delta V}$ is the command and display system

$\Delta V_{\text{Override}}$[a] - Confirmation capability allowing the maneuver integration to stop on the specified ΔV.

$\Delta t_{\text{Override}}$[a] - Confirmation capability allowing the maneuver integration to stop on the specified Δt.

c) Burn Parameters for P3 - ΔV vector in the IMU coordinate system

Example: M40,/P3, $\dot{X}$, $\dot{Y}$, $\dot{Z}$,/;

$\dot{X}$, $\dot{Y}$, $\dot{Z}$ - V_{gx}, V_{gy}, V_{gz} in the IMU coordinate system

d) Burn Parameters for P4 - ΔV vector in the LVLH coordinate system

Example: M40,/P4, $\dot{X}$, $\dot{Y}$, $\dot{Z}$/;

$\dot{X}$, $\dot{Y}$, $\dot{Z}$ - V_F, V_S, V_D in the LVLH coordinate system

e) Burn Parameters for P5 - Lambert targets

Example: M40,/P5, X, Y, Z, $\begin{Bmatrix}\text{MCI}\\\text{ECI}\end{Bmatrix}$ Indicator, Time of Flight to Target Vector, Steering Constant, ΔV, Δt/;

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[a]For direct input of future maneuvers the $\Delta V_{\text{Override}}$ and $\Delta t_{\text{Override}}$ are not allowed.

X, Y, Z - ECI or MCI target vector

ECI / MCI Indicator - Indicates in which system the target vector is given

Time of Flight to Target Vector - Time from ignition to arrival at target vector

Steering Constant - Cross-product steering constant

$\Delta V_{Override}$ - For confirmation - to allow the maneuver integration to stop on the desired ΔV input

$\Delta t_{Override}$[a] - Confirmation capability - allowing the maneuver integration to stop on the desired Δt input

f) Burn Parameters for P6 - ΔV_X, ΔV_Y, ΔV_Z - ΔV residuals are used for confirmation only.

II. M66, TABLE CODE, MANEUVER SEQUENCE NUMBER, GETBI, THRUSTER, ATTITUDE, BURN PARAMETER NUMBER, COORDINATE INDICATOR, PITCH, YAW, ROLL, Δt_{ULLAGE}, NUMBER OF ULLAGE THRUSTERS, HEADS UP/DOWN INDICATOR, Δt 10% DPS THRUST, REFSMMAT, CONFIGURATION CHANGE INDICATOR, FINAL CONFIGURATION, Δ DOCKING ANGLE;

Table Code - CSM or LEM depending on which ephemeris is to contain the maneuver

Maneuver Sequence No. - If it is desired to replace an existing maneuver with the one being input, the sequence number of the maneuver being replaced should be input.

GETBI - Ground elapsed time to begin thrusting, this is main engine on time for SPS, APS, DPS maneuvers.

Thruster - a) Code for CSM Thrusters:

C1 - RCS+X 2 quads
C2 - RCS+X 4 quads
C3 - RCS-X 2 quads
C4 - RCS-X 4 quads
S - SPS

---

[a]For direct input of future maneuvers the $\Delta V_{Override}$ and $\Delta t_{Override}$ are not allowed.

b) Code for LM Thrusters:

L1 - RCS+X 2 quads
L2 - RCS+X 4 quads
L3 - RCS-X 2 quads
L4 - RCS-X 4 quads
A - APS
D - DPS

c) Code for S4B "Blowdown" Vent - BV

Attitude -a) Attitude Control Mode for CSM:

I - Inertial (Thrust direction fixed in inertial space)
M - Manual (Holding the body orientation fixed in inertial space)
EP - Primary External ΔV
L - Lambert Guided

b) Attitude Control Mode for LM:

L - Lambert Guided
I - Inertial (see above)
M - Manual (see above)
EP - Primary External ΔV
EA - AGS External ΔV

Burn Parameter - Numeric Code from 1 to 5[a] where:

1 corresponds to P1 burn parameters
2 corresponds to P2 burn parameters
3 corresponds to P3 burn parameters
4 corresponds to P4 burn parameters
5 corresponds to P5 burn parameters

Coordinate Indicator - Indicator to denote in which coordinate system the S/C attitude angles are given.

L - Local Vertical, Local Horizontal
I - IMU
Pitch - Pitch angle in degrees at GMTI
Yaw - Yaw angle in degrees at GMTI
Roll - Roll angle in degrees at GMTI

Δt of Ullage - Number of seconds of RCS thrust for ullage

Number of Ullage Thrusters - Number of quads to be used in the ullage thrusting: 2 or 4

---

[a] 6 corresponds to P6 target parameters; these are valid <u>only</u> for confirmation.

Heads Up/Down Indicator	- Vehicle orientation for the maneuver: U = Heads up D = Heads down
Δt 10% Thrust for DPS	- Number of seconds to thrust at the 10% level for DPS maneuvers.
Refsmat	- ID of the Refsmat that is desired for the maneuver computations.
Configuration Change Ind.	- To indicate if the maneuver is to change the vehicle configuration: NC - No change U - Undocking D - Docking
Final Configuratin	- Configuration code at the end of this maneuver: C - CSM L - LM CL - CSM/LM CS - CSM/S-IVB LS - LM/S-IVB CSL - CSM/LM/S-IVB A - LM Ascent D - LM Descent
ΔDocking Angle	- An increment to be used to change the nominal docking angle.

(c) MANEUVER CONFIRMATION

M60,(Same format as M66 except one additional quantity which follows the ΔDocking Angle Parameter).

Additional Parameter - Trim Angle Indicator:
C = Compute trim angles
S = Use system parameter values for trim angles

Also for confirmation the M40 burn parameter P6 can be used.

(d) TLI MANEUVER CONFIRMATION

M61, TABLE MANEUVER SEQUENCE NUMBER, THRESHOLD TIME, Δt BURN DURATION;

Table Code	- CSM or LEM MPT
Maneuver Sequence Code	- Sequence number of the maneuver being confirmed
Threshold Time	- Ignition time for the maneuver
Δt Burn Duration	- Δt at which the maneuver integration ceases.

TABLE II.- MPT1 SYMBOLS

(a) Input symbols[a]

ABC(I,J)	Array into which all of the input to the MPT1 is stored. This input will consist mainly of impulsive maneuver parameters calculated in the processors which input to the MPT. The "I" subscript identifies the maneuver sequence of the incoming set while the "J" subscript identifies individual parameters for the "I" th maneuver. See section "MPT1" in text.
KDEL	Code of the MPT maneuver which is to be deleted. A value of 0 or -1 means no deletions.
KID	Flag which identifies the planning-aid processor (including direct input) which originated the maneuver.
kk3	Code of the MPT maneuver which is to be replaced by the present input maneuver.
K201I	Total number of maneuvers in the present input set.
K55, K56	Maneuver code of the latest LM and CSM maneuvers, respectively, which are to be frozen. All maneuvers for each vehicle prior to this time are frozen.
LI	Maneuvering vehicle.
TI	Impulsive maneuver time.

(b) Output symbols

ABCDE(I,J)	Array into which all display and stored variables are kept. Maneuvers stored here are time ordered. Subscript "I" identifies the maneuver. Subscript "J" identifies individual parameters associated with the "I"th maneuver. See section "MPT1" in text.

[a]The input table used by IBM will probably differ considerably from this list.

TABLE II.- MPT1 SYMBOLS - Continued

K203	If = -1, indicates a new maneuver which must be passed through the powered flight integrator. If = +1, indicates a maneuver which has already passed through the powered flight integrator and has been displayed. Its powered flight parameters can be called from ABCDE.
K3MAX	Total number of maneuvers to be displayed on MPT.
	(c) Internal symbols
ABCD(I,J)	Array containing the same variables found in ABCDE. Maneuvers in this array are not time ordered. See section "MPT1" in text.
FREZT	Time of latest frozen maneuver for each vehicle. Subscripts identify the vehicle.
KINT	If = -1, indicates a new maneuver which must be passed through the powered flight integrator. If = +1, indicates a maneuver which has already passed through the powered flight integrator and has been displayed.
KSE, KSEQ	Sequence number of a maneuver being displayed on the MPT. This number is based on the time-ordered sequence.
K21	Same as KSEQ.
K200	Number of the next maneuver to be stored in ABCD.
K201	Total number of maneuvers in the small table (ABCD).
K201II	Stored value of K201I.
K207	Number of maneuvers that have currently been time ordered.
L, LV, LR	Vehicle designator: if = 1, indicates LM; if = 2, indicates CM.

TABLE II.- MPT1 SYMBOLS - Concluded

M_{array}	Total number of parameters in table ABC for each maneuver.
N_{array}	Total number of parameters in table ABCD for each maneuver.
δ_1, δ_2	Flags used in determining the first maneuver for each vehicle in the input maneuver set.
δ_4	Flag indicating whether or not the first maneuver has been considered in the time-ordering process.
TC	Time of the maneuver currently being time ordered.
TFIR	Time of the first maneuver of each vehicle in the input set.
TM	Impulsive maneuver time in ABCDE.
TR	Impulsive maneuver time in ABCD.

TABLE III.- MPT2 SYMBOLS

(a) Input symbols

ABCD, ABCDE	See definition in table II(b and c).
DTTO	Thrust model value of Δt of tailoff.
ELSAV	Vector for each vehicle before first MPT maneuver in the current update.
ENO	Number of RCS thrusters employed for maneuver; this must be set even if RCS thrusters are only used for ullage.
K_{ID}	Flag which identifies the planning-aid processor which originated the maneuver.
GASL	Propellant weight for each engine before first MPT maneuver in the current update; subscripts identify the engine.
D	Docking angle.
IDOCK	If = +1, indicates that vehicles are docked throughout the maneuver. If = -1, 0, indicates that vehicles are not docked throughout the maneuver.
IVH	If = +1, sets full thrust profile in integrator. If = -1, 0 sets thrust profile to be only one phase (i.e., no ullage, buildup or tailoff).
JJ	Indicates which thruster is to be used.
KATTOP	Identifies which attitude control is used. Same as moded.
KAXOP	Identifies the thrust translational axis along which the maneuver is applied.
K_{ITER}	If = +1, indicates that the maneuver is to be iterated. If = -1, 0, indicates that iteration is to be bypassed.

TABLE III.- MPT2 SYMBOLS - Continued

KRCSS	If = +1, indicates RCS thrusters did the maneuver. If = 0, 1, indicates RCS thrusters did not do the maneuver.
KROLLS	If = +1, heads-down attitude. If = -1, heads-up attitude.
KREF	If = 1, indicates earth orbit. If = 2, indicates lunar orbit.
KTUP	If = +1, indicates that MPT is being updated by the TUP. If = -1, 0, indicates that MPT is having new maneuvers added.
K3MAX	Total number of maneuvers in the MPT.
K203	If = -1, current maneuver is to be integrated. If = +1, current maneuver has already been integrated and its powered flight parameters can be taken from ABCDE.
μ	Gravitational constant.
R_e	Equatorial radius of reference body.
R_p	Polar radius of reference body.
R_{REF}	Radius of launch pad for an earth orbit; radius of landing site for a lunar orbit.
REFSMMAT	Matrix-relating platform (IMU) to basic reference coordinate system.
THTARG	Δtrue anomaly from impulsive maneuver point to target point.
TSAV	Time of vector taken from ELSAV array.
TUPI	Time of input state vector to be used when the update route requires the onboard state vector to be input.
ULOVLP	Δt from main engine ignition until ullage thrust termination.
UT	Ullage thrust duration.

TABLE III.- MPT2 SYMBOLS - Continued

WHTSAV	Weight of vehicle at time of the state vector defined by ELSAV.
	(b) Output symbols
AV_X, AV_Y, AV_Z	ΔV targeting parameters for AGS in AGS coordinate system.
δ	Wedge angle at cutoff between CSM and LM (S-IVB) orbits; positive when inclination of maneuvering vehicle is less than the passive, deg.
δ_p	Wedge angle between orbit at cutoff and a parallel plane passing through the lunar landing site, displayed in degrees and positive when the orbital inclination is greater.
δ'_p	Main engine pitch gimbal at ignition.
δ_y	Main engine yaw gimbal at ignition.
e	Orbital eccentricity after cutoff.
GET	Ground elapsed time of impulsive maneuver.
GETCO	Ground elapsed time of main engine cutoff.
GETI	Ground elapsed time of main engine ignition.
Δh	Differential altitude at cutoff between LM (S-IVB) and CSM, displayed in nautical miles and positive when maneuvering vehicle is below.
h_a	Altitude of next apoapsis after cutoff above spherical reference.
h_{BI}	Altitude of maneuvering vehicle above oblate earth or moon (defined by REF) at ignition.
h_p	Altitude above spherical reference of next periapsis after cutoff.
i	Trajectory inclination to earth or moon (defined by REF) plane at cutoff.
I	Inner gimbal angle (0-360°) at ignition based on prethrust information.

TABLE III.- MPT2 SYMBOLS - Continued

$\dot{\theta}$	Rate of change of phase angle at cutoff, positive when θ is decreasing, deg per orbit.
θ_p	Central angle between radius vector passing through the next pericynthion after cutoff and the lunar landing site at the time of next pericynthion, displayed in degrees and negative when the landing site is beyond pericynthion.
θY_{θ}, θZ_{ψ}, θX_{ϕ} [a]	Inner, middle, and outer gimbal angles of the ST-124 at ignition, deg. These parameters will be displayed in the targeting portion of the DMT for TLI only.
Δt_B	Duration of main engine burn, min:sec.
Δt_{to}	Effective duration of main engine tailoff, sec.
Δt_u	Duration of ullage, sec.
ΔV_C	Total velocity increment less tailoff to be sensed along CSM X-axis, fps.
ΔV_M	Total velocity increment of maneuver, fps.
ΔV_{REM}	Total ΔV capability for the maneuvering vehicle remaining after maneuver, fps.
ΔV_{TO}	Velocity increment of main engine tailoff, fps.
V_F, V_D, V_S	For Lambert maneuver, the prethrust velocity-to-be-gained vector defined at T_{IG} and rotated into the local horizontal coordinate system. For all other maneuvers, a vector whose direction is along the prethrust thrust vector defined at T_{IG} and whose magnitude is equal to the target ΔV magnitude. This vector is rotated into the local horizontal system.
V_{gx}, V_{gy}, V_{gz}	This is the vector defined by V_F, V_D, V_S except it is now expressed in the IMU coordinate system instead of local horizontal.
V_X, V_Y, V_Z	ΔV targeting parameters for PGNS in PGNS coordinate system.

[a]Input to MPT2 from outside processor and displayed without modification.

TABLE III.- MPT2 SYMBOLS - Continued

kaxopp	Identifies axis along which translation was performed.
λ_{AN}	Longitude of next ascending node after cutoff.
λ_{BI}	Longitude of maneuvering vehicle at ignition.
λ_{LLS}[a]	Longitude of lunar landing site, deg:min
M	Middle gimbal angle (0-360°) at ignition based on prethrust information.
η_{BI}	True anomaly of maneuvering vehicle at ignition.
O	Outer gimbal angle (0-360°) at ignition based on prethrust knowledge.
W_p	Argument of perigee or pericynthion (defined by REF) resulting from maneuver.
P_B	FDAI pitch angle (0-360°) at ignition for LM only.
P_H	Local vertical-local horizontal pitch angle at ignition based on prethrust information, deg.
ϕ_{BI}	Geodetic latitude of maneuvering vehicle at ignition.
ϕ_{LLS}[a]	Latitude of lunar landing site.
R_B	FDAI roll angle (0-360°) at ignition for LM only.
R_H	Local verical-local horizontal roll angle at ignition based on prethrust information, deg.
r_{LLS}[a]	Radius of lunar landing site, n. mi.
Ruster	Indicates which thruster was used.
θ	Phase angle (0°-360°) at cutoff between LM (S-IVB) and CSM measured from chaser to target in the direction of motion.

[a]Input to MPT2 from outside processor and displayed without modification.

TABLE III.- MPT2 SYMBOLS - Continued

V_P	Velocity at next pericynthion after maneuver, fps.
W_C	CSM inert weight, lb.
W_F	Weight prior to the maneuver of the propellant of the engine performing the maneuver, lb.
W_L	LM inert weight, lb.
W_T	Weight of the total vehicle (S-IVB/CSM/LM, CSM/LM, CSM, or LM) prior to the maneuver, lb.
Y_B	FDAI yaw angle (0°-360°) at ignition for the LM only.
YD	Cross-range distance from CSM orbit to LM at insertion, n. mi.
Y_H	Local vertical-local horizontal yaw at ignition based on prethrust information, deg.

(c) Internal symbols

a	Semimajor axis at burn cutoff.
A_{TBI}	Unit vector calculated during prethrust in the direction of the thrust vector defined at T_{IG}.
α	Angular difference between 1/2 of burn arc calculated by the onboard external ΔV program and the angle measured between the main engine thrust initiation point and the impulsive maneuver point.
AN	Mean motion of active vehicle.
AO	Six-dimensional array of orbital elements before impulsive maneuver.
AP	Six-dimensional array of orbital elements after impulsive maneuver.
CSMPOS, CSMVEL	CSM position and velocity vectors, respectively.
DEC	Declination.

TABLE III.- MPT2 SYMBOLS - Continued

δ_{ITER}	If = +1, indicates that the maneuver is to be iterated. If = 0, -1, indicates that iteration should be bypassed.
DTU	Δt used in iterations to find time of crossing the ascending node.
DVR	ΔV capability remaining in this vehicle after current maneuver.
ENOP	Value of ENO at last MPT update.
ε_{LOI}	Orbital eccentricity tolerance for LOI maneuvers. If the eccentricity is less than this tolerance, the angle between the impulsive point and the burnout orbit pericynthion vector is omitted as as an iteration variable.
ε_{GPMP}	Orbital eccentricity tolerance for GPMP maneuvers. If the eccentricity is less than this tolerance, argument of perigee is omitted as an iterating variable.
FREZT	Latest frozen maneuver time for each vehicle; subscript identifies vehicle.
FRCRCS, FRCSPS, FRLRCS, FRLDPS, FRLAPS	Fuel remaining after current maneuver in the CSM RCS, CSM SPS, LM RCS, LM DPS, and LM APS tanks, respectively.
GN	Time derivative of the argument of perigee.
h_1, h_2	Ascending node of LM and CSM orbits, respectively.
$\overline{H}_{CO}$	Unit vector along the angular momentum vector of the active vehicle at thrust cutoff.
H'	Unit vector perpendicular to the plane defined by the lunar landing site (defined at GETCO) and a vector parallel to the active vehicle plane.
$\overline{H}_{PAS}$	Unit vector along the angular momentum vector of the passive vehicle defined at the time of thrust cutoff.

TABLE III.- MPT2 SYMBOLS - Continued

i_1, i_2	Inclination of LM and CSM orbits, respectively.
IVEH, IVEHP	Same as input IVH.
J3	Index number of input maneuvers.
Kaxis	Identifies the RCS translational axis along which thrust is applied.
K_L	Number of the passive vehicle.
Kon	If = +1, indicates that MPT update requires double integration for the current maneuver. If = -1, indicates regular integration is sufficient.
KRCS, KRCSSP	Same as input KRCSS.
KROLL, KROLLP	Same as input KROLLS.
K_3	Number of the current maneuver being processed.
K_4	K_3 number of the last maneuver of the passive vehicle prior to the current maneuver being processed.
K6	Number of current maneuver per vehicle; for example, if K6(1) = 3, indicates the current maneuver is the third LM maneuver.
K210	Gives the K3 for any maneuver when the vehicle and maneuver number for this vehicle is known. For example, if K210(3,2) = 5, then the fifth MPT maneuver was the third maneuver performed by the CSM.
K212	Gives the maneuver number per vehicle, when the K3 is known. For example, if K212(5,1) = 3, then the fifth maneuver in the MPT was the third maneuver performed by the LM.
L	Active number: if = 1, indicates LM. if = 2, indicates CSM.
LK3	K3 number of the previous maneuver for the active vehicle.

TABLE III.- MPT2 SYMBOLS - Continued

L6	Equals the current K6 number for the active vehicle.
L6m	Equals the previous K6 number for the active vehicle.
LVLH	Matrix which translates an ECI or MCI vector into a local horizontal coordinate system at thrust ignition.
n_t, n_c	Mean motion for the target and chaser, respectively.
$\bar{P}_{POS}$	Position vector of passive vehicle.
$\bar{P}_{VEL}$	Velocity vector of passive vehicle.
$\bar{R}_{BI}$	Radius vector of active vehicle at thrust ignition calculated during prethrust.
$\bar{R}_{CO}$	Radius vector of active vehicle at thrust cutoff.
$\bar{R}_{LS}$	Lunar landing site vector.
$\bar{R}_{UL}$	Radius vector of active vehicle at ullage thrust ignition.
$\bar{r}_2$	Target radius vector for Lambert cross-product steering.
T_F	Time of flight to conic target aim vector.
T_{IG}	Time of main engine ignition.
Timp	Impulsive maneuver time.
T_{AL}	Time of last impulsive maneuver for passive vehicle prior to current maneuver being processed.
Tm	Impulsive maneuver time.
TSTART	Vector time used to define orbit prior to current maneuver.

TABLE III.- MPT2 SYMBOLS - Continued

Tu	Time of crossing of first ascending node after burn cutoff.
Tui	Time of ullage engine ignition.
Tup	Time of vector used in update.
U(L)	Burnout argument of latitude of active vehicle.
$\overline{U}_1$	Unit vector along LM radius vector at ullage thrust ignition.
$\overline{U}_z$	Unit vector along polar axis of the reference body.
ΔU	Increment of argument of latitude.
$\overline{V}_1$	Unit vector perpendicular to $\overline{U}_1$, parallel to CSM orbit plane, and pointing in the direction of the LM motion.
$\overline{V}_{CO}$	Active vehicle's velocity vector at thrust cut-off.
$\overline{\Delta V}_{CO}$	ΔV vector of maneuver from ullage initiation to main engine cutoff.
$\overline{\Delta V}_I'$	Prethrust unit vector directed along the thrust vector defined at T_{IG}.
$\overline{\Delta V}_{LS}$	Vector perpendicular to the lunar landing site but parallel to the CM orbit plane.
ΔV_{wt}	Magnitude of ΔV at main engine cutoff.
$\overline{W}_1$	$\overline{U}_1 \times \overline{V}_1$.
W_{csm}	Angular momentum vector of CSM orbit.
WHT	Vehicle weight.
WTLME	Weight of propellant used by the main engine during a maneuver.
WTLUE	Weight of propellant used by the ullage engine during a maneuver. This value is zero for an RCS maneuver.

TABLE III.- MPT2 SYMBOLS - Concluded

XIND	If = 1, indicates pitch at main engine ignition. If = 2, indicates yaw at main engine ignition. If = 3, indicates main engine burn duration. If = 4, indicates Δt between main engine ignition and impulsive maneuver time.
Xmm	Mean anomaly at conic target aim point.
Xnn	Mean motion.

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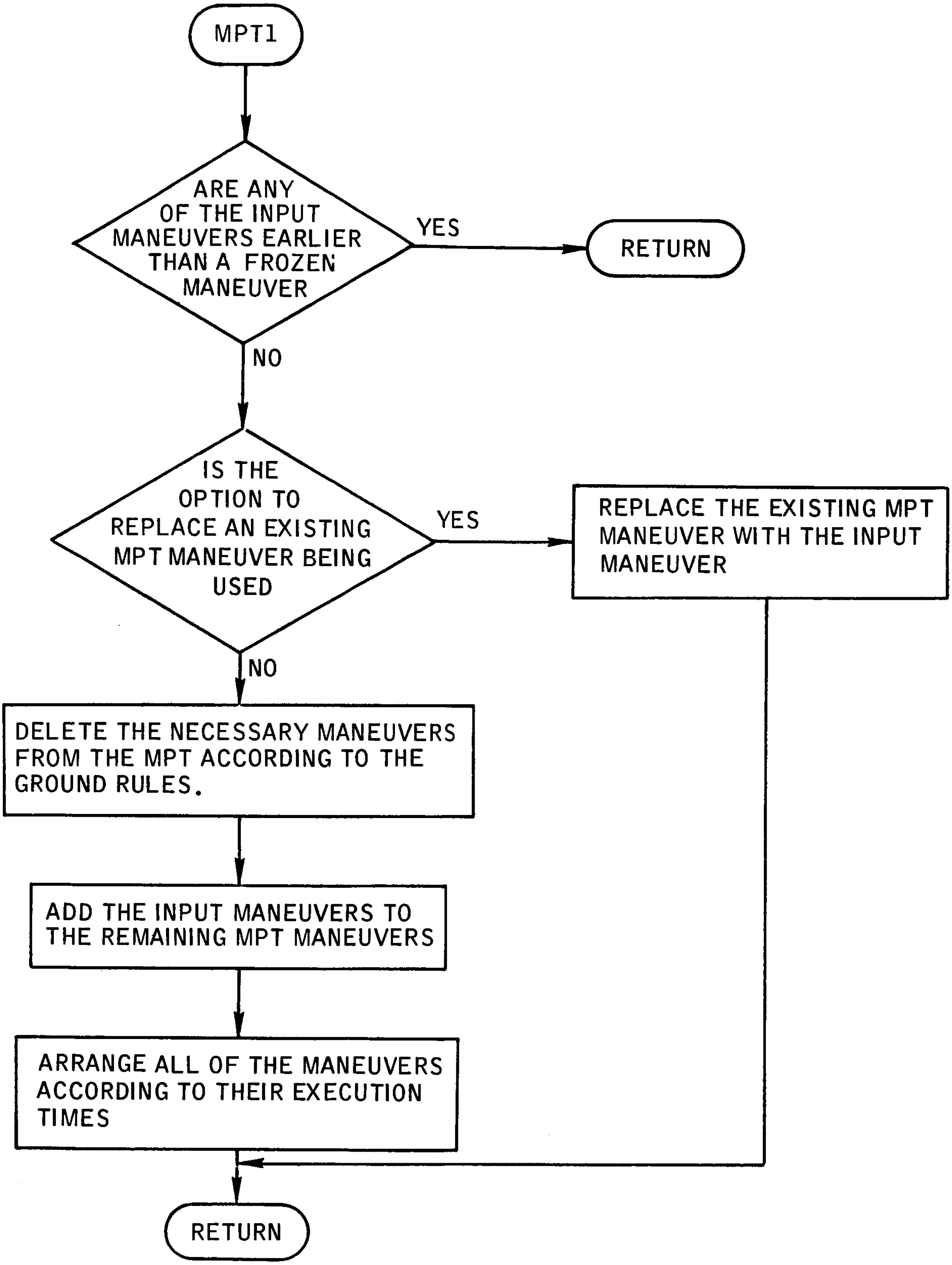
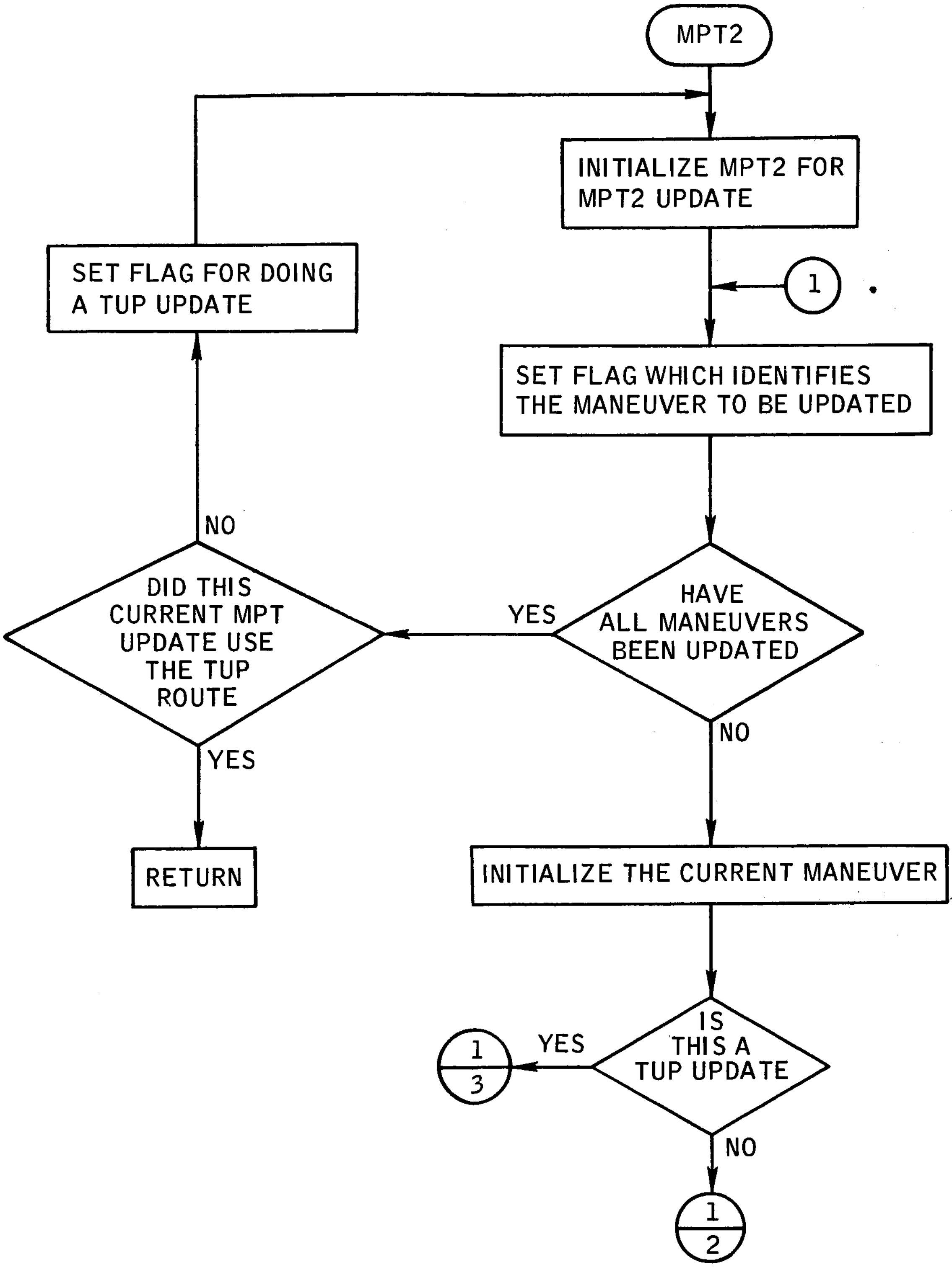
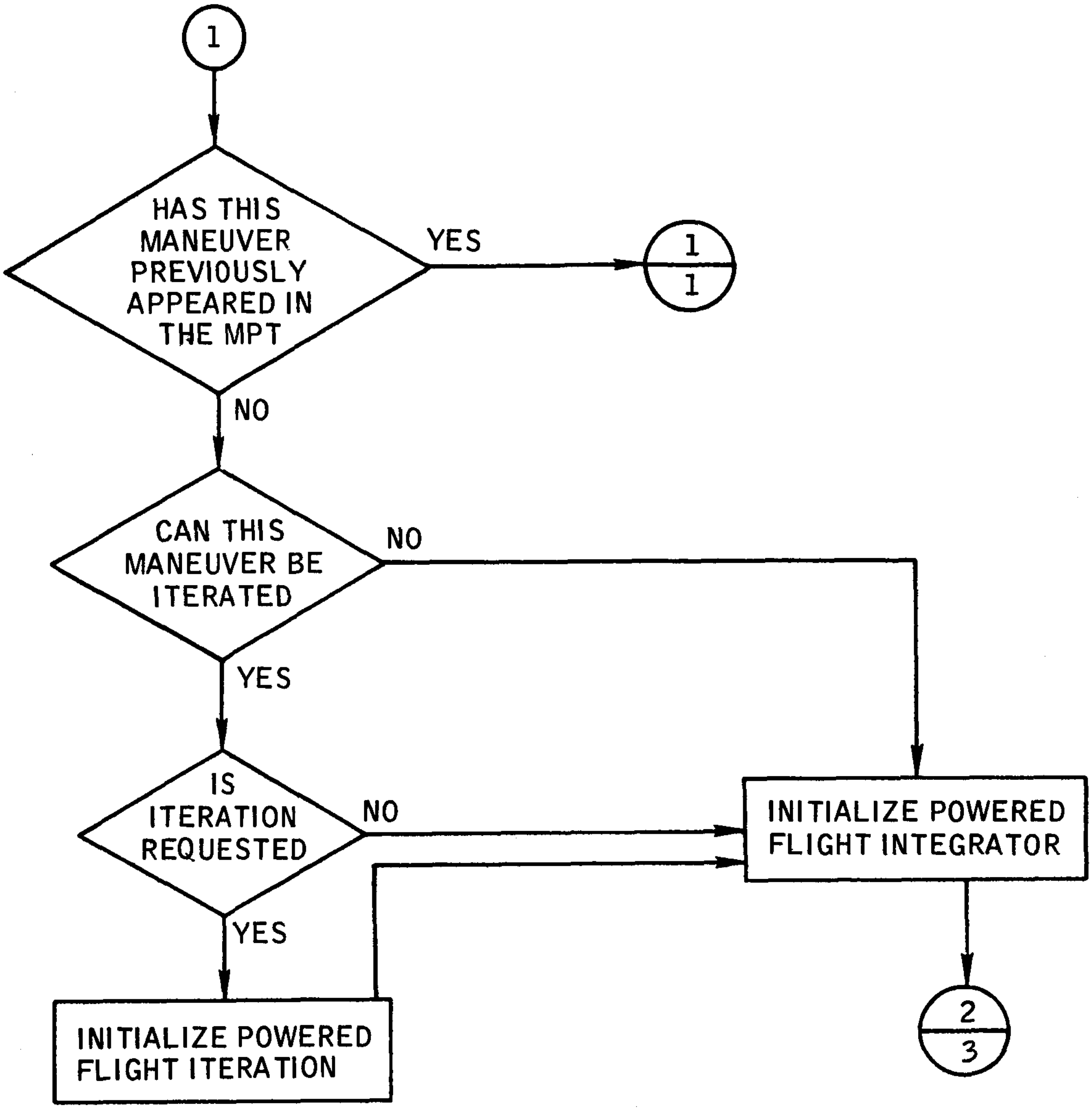


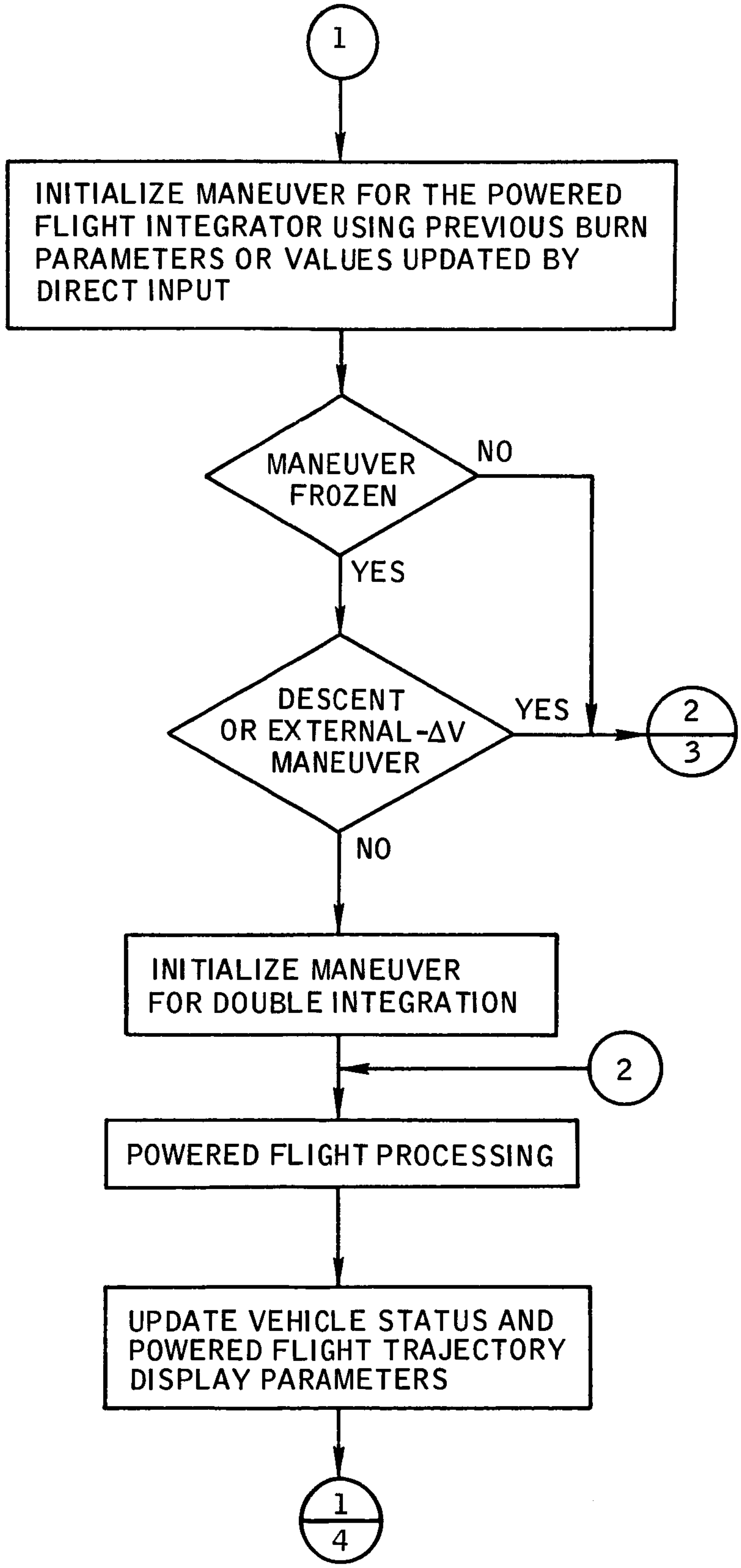
Flow chart 1.- Functional flow for MPT1.



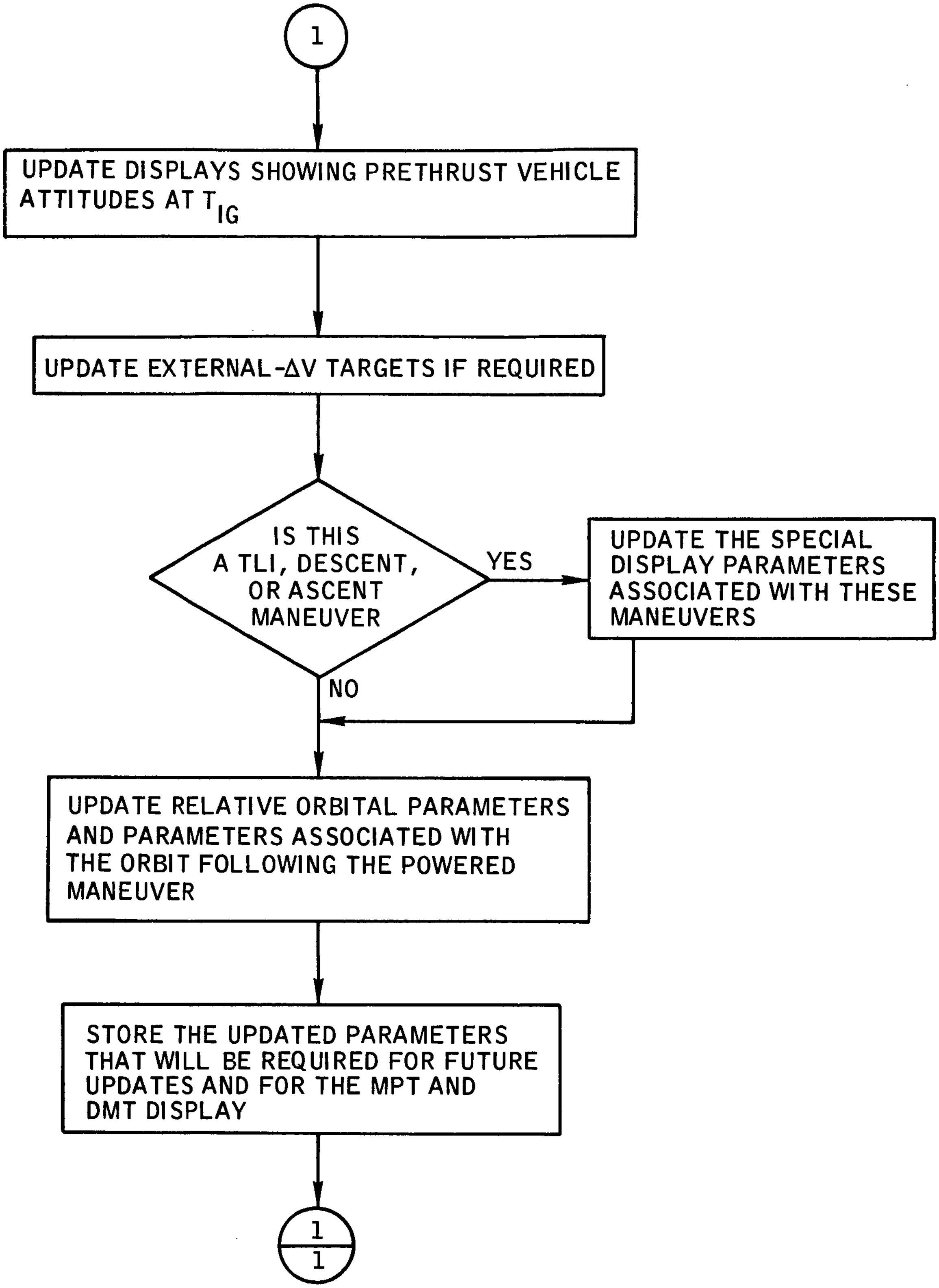
Flow chart .- Functional flow for MPT2



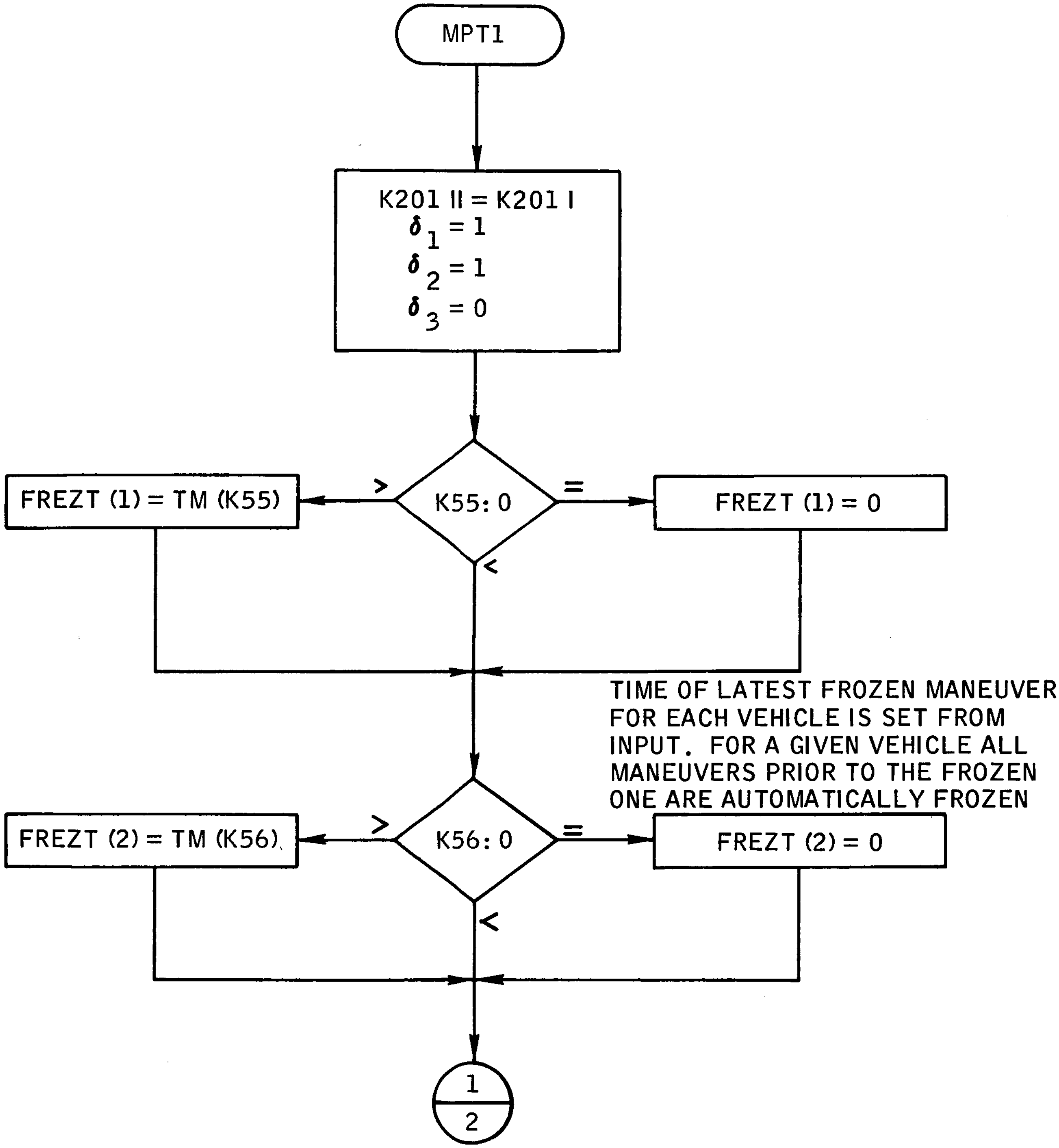
Flow chart .- Functional flow for MPT2 - Continued.



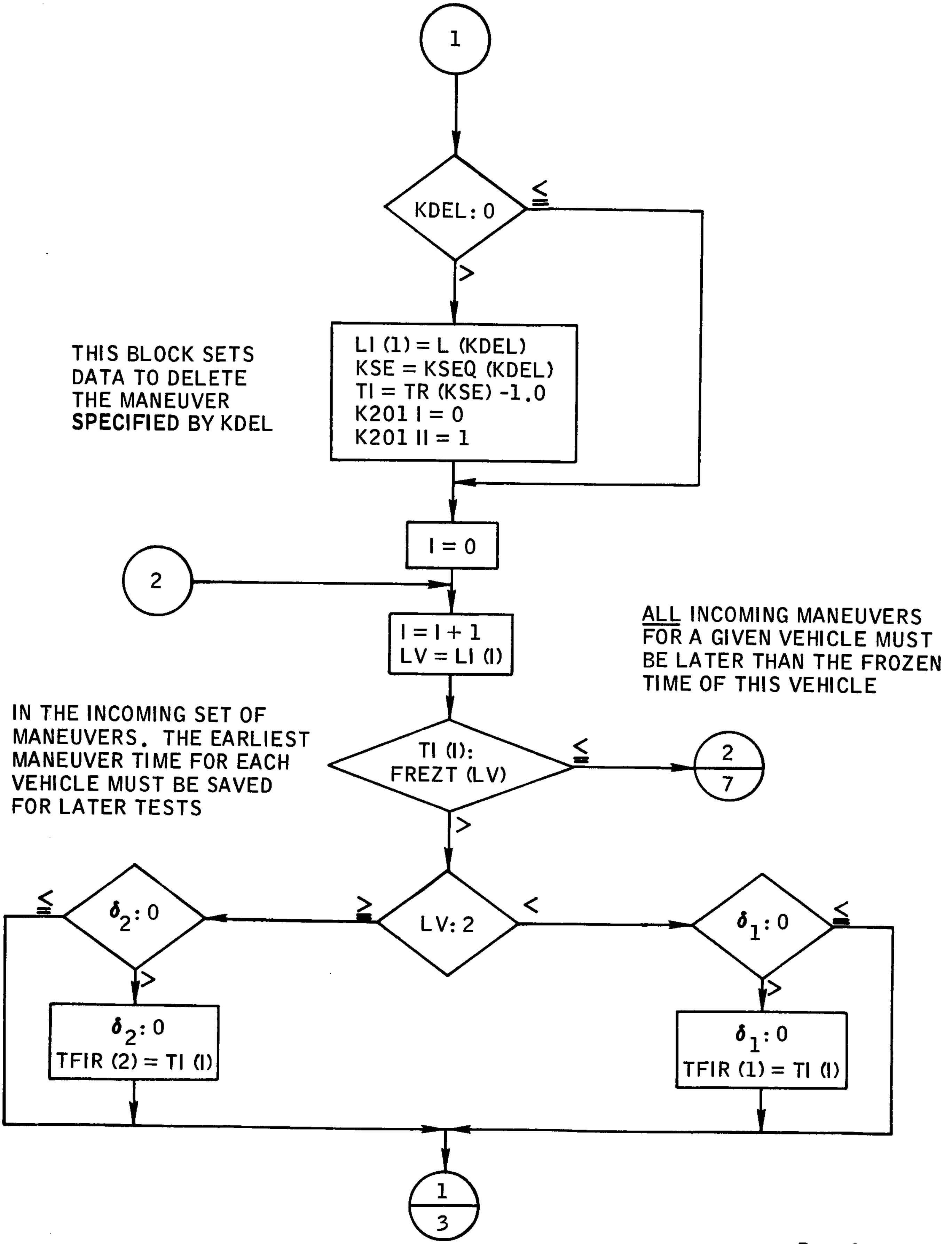
Flow chart .- Functional flow for MPT2 - Continued.



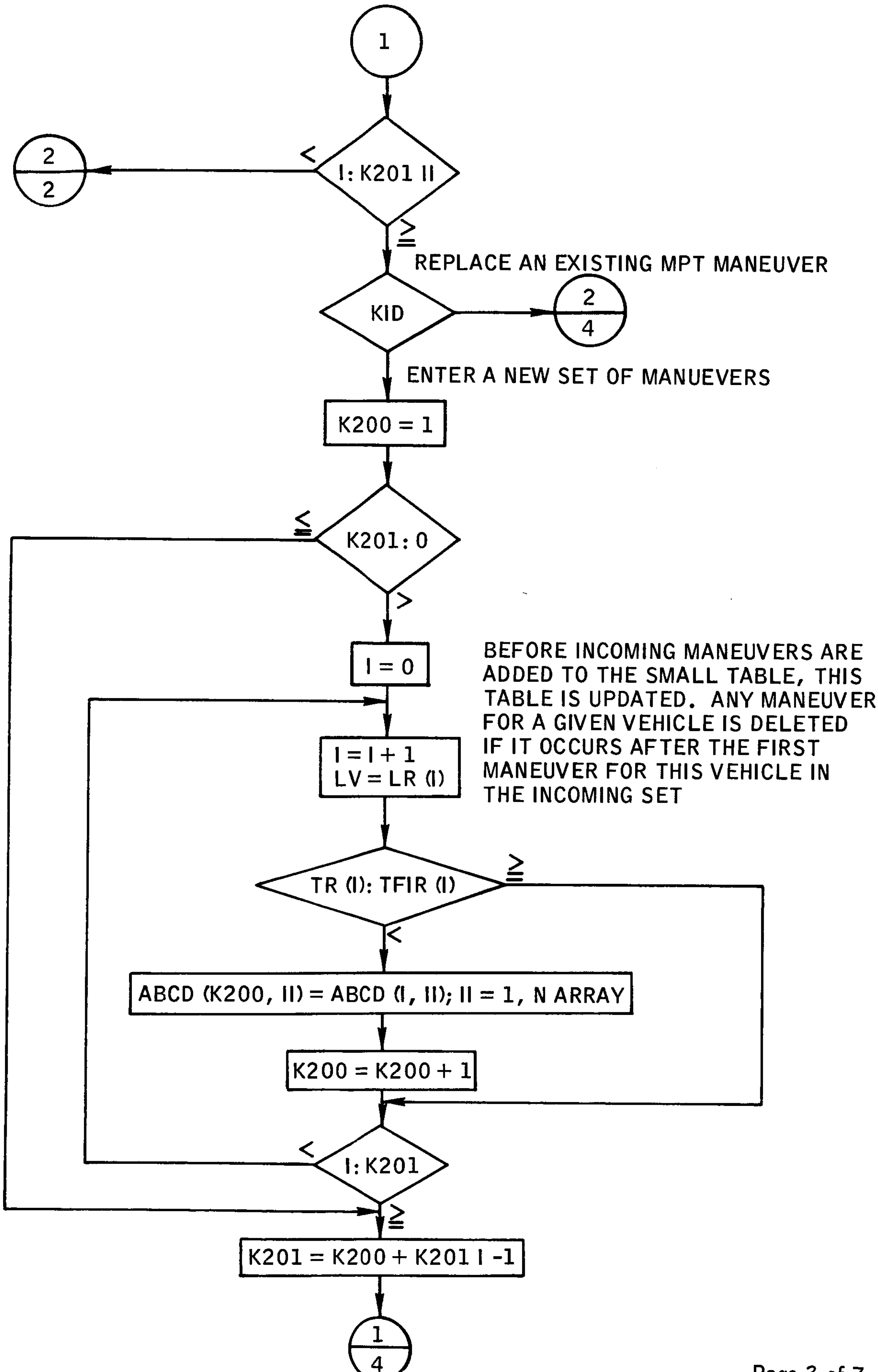
Flow chart .- Functional flow for MPT2 - Concluded.



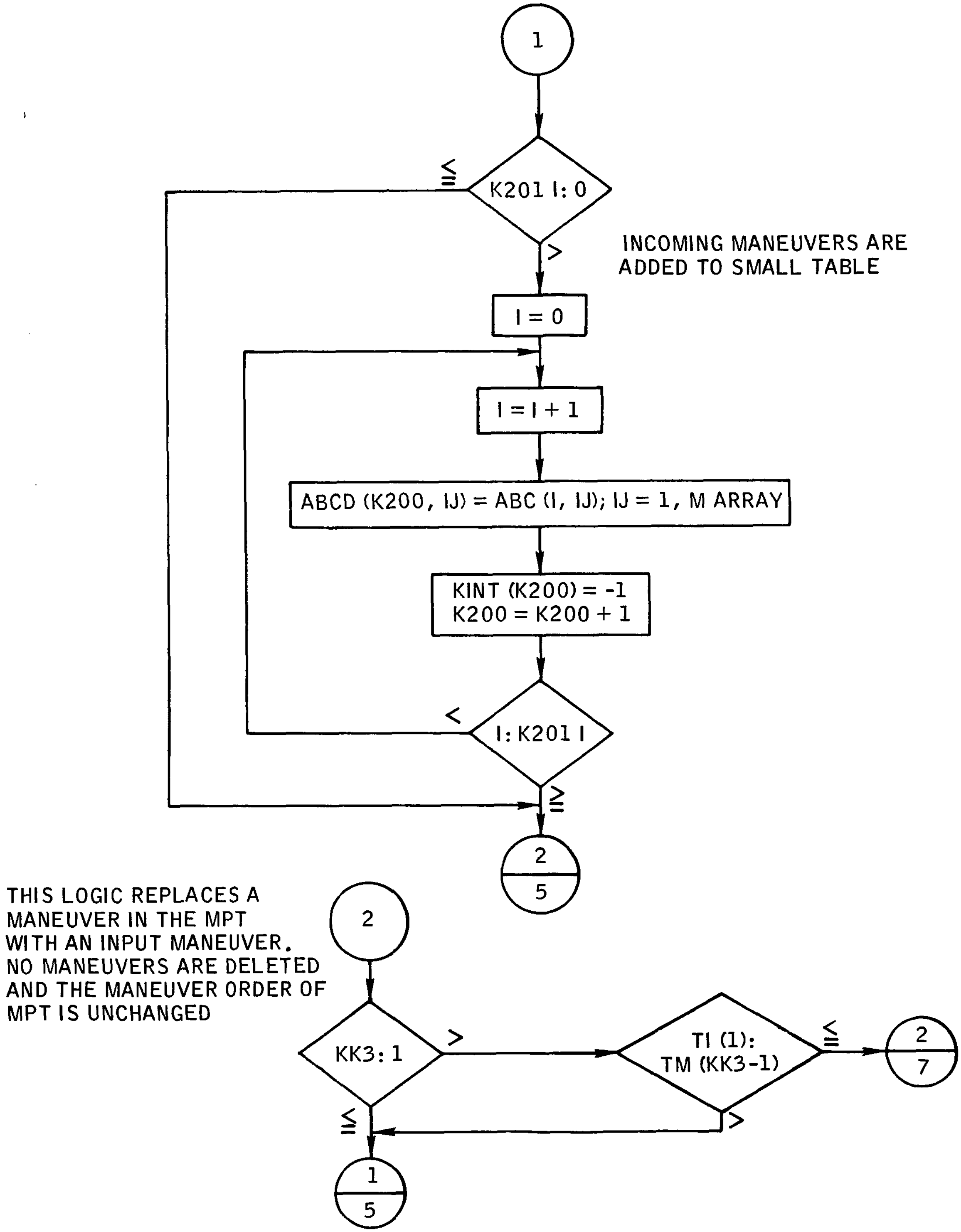
Flow chart .- Detailed flow for MPT1.



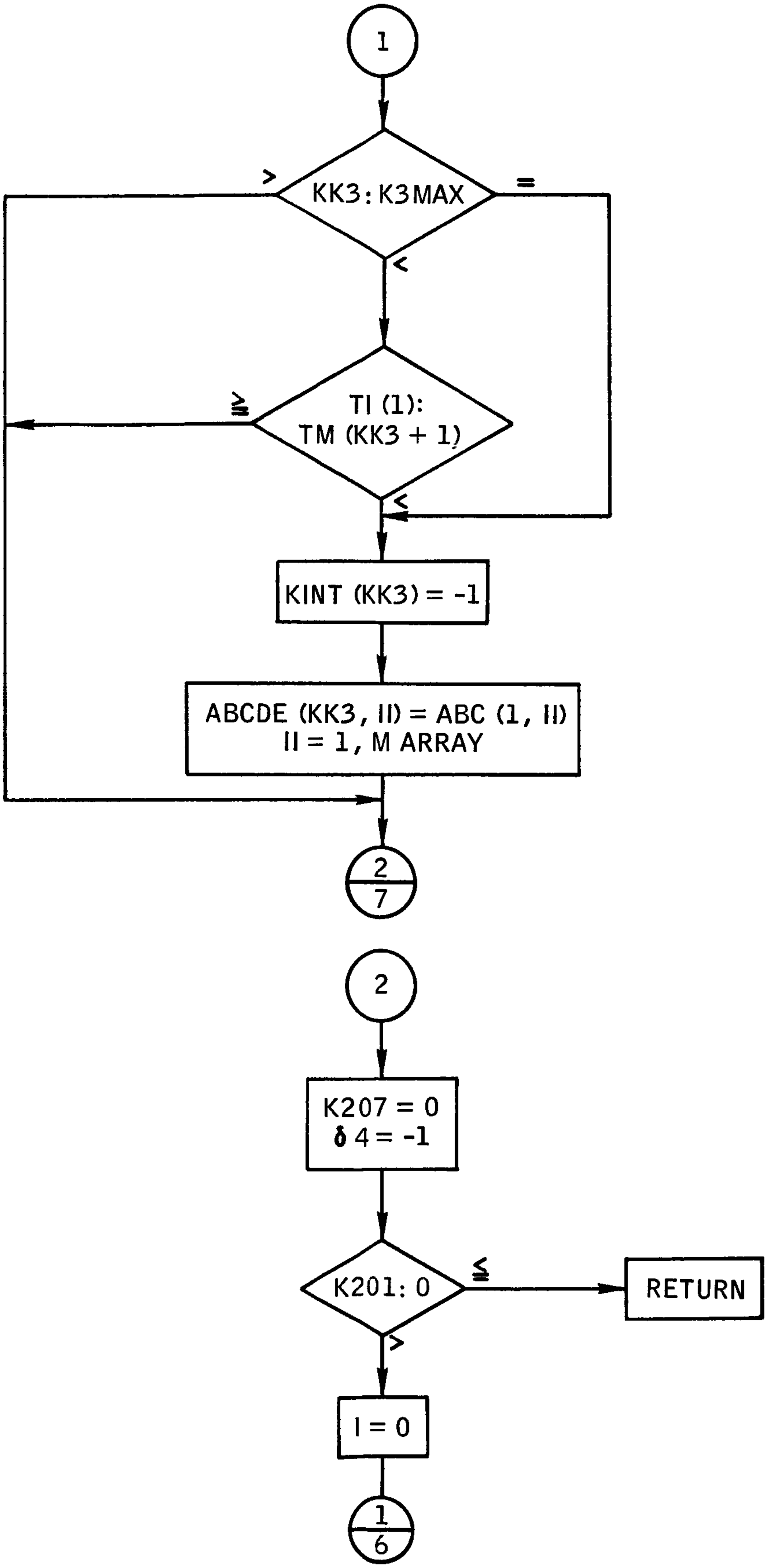
Flow chart .- Detailed flow for MPT1 - Continued.



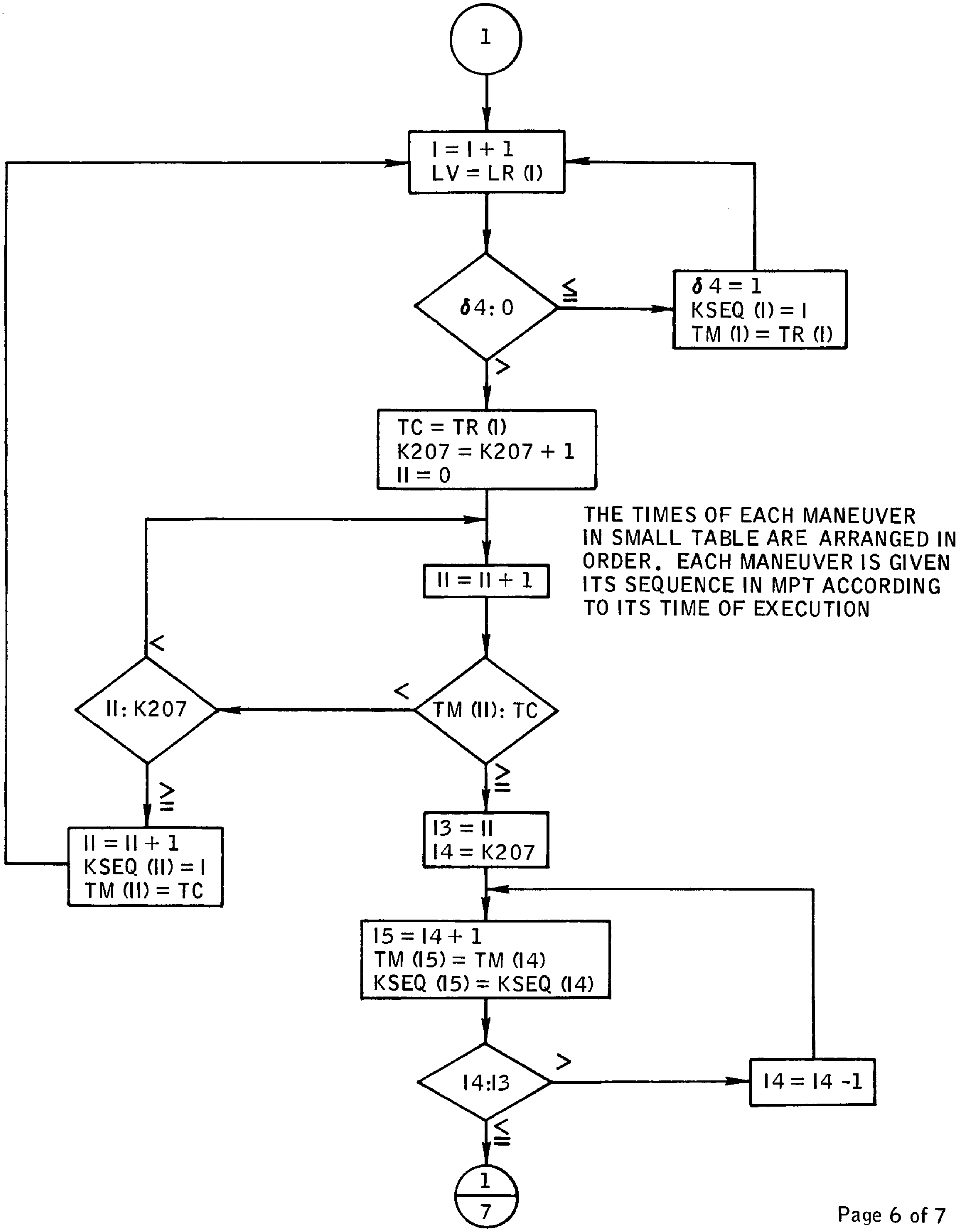
Flow chart .- Detailed flow for MPT1 - Continued.



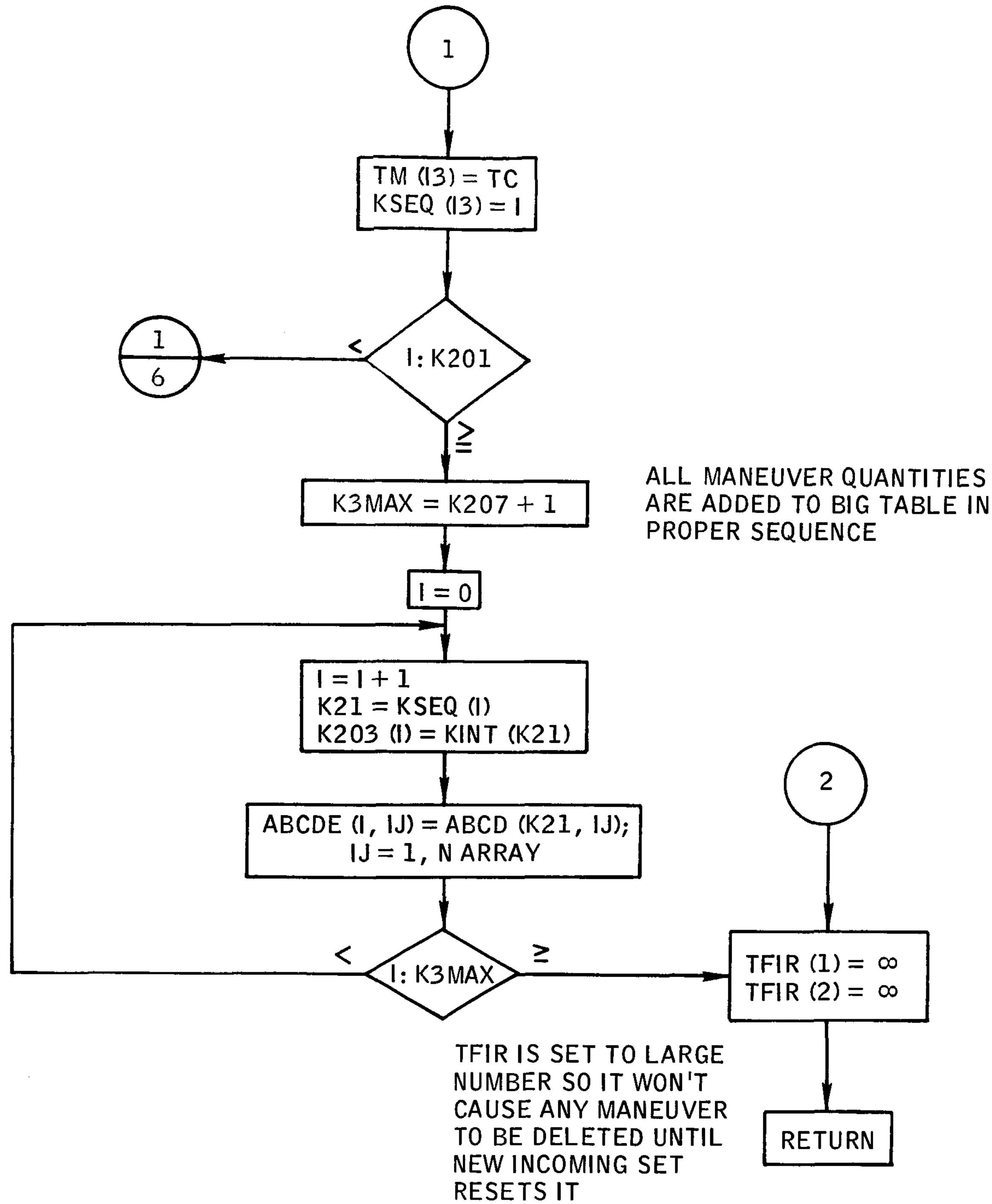
Flow chart .- Detailed flow for MPT1 - Continued.



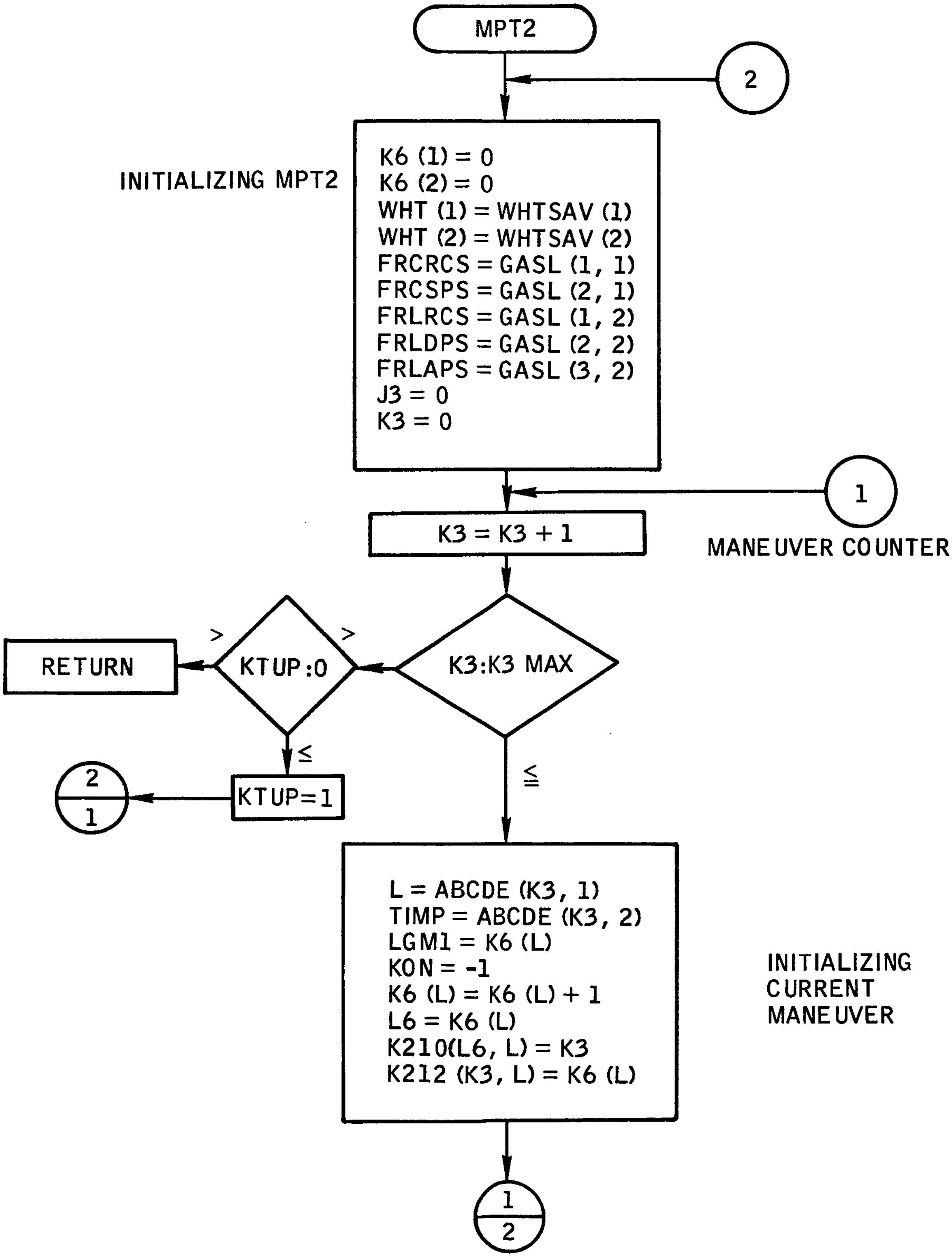
Flow chart .- Detailed flow for MPT1 - Continued.



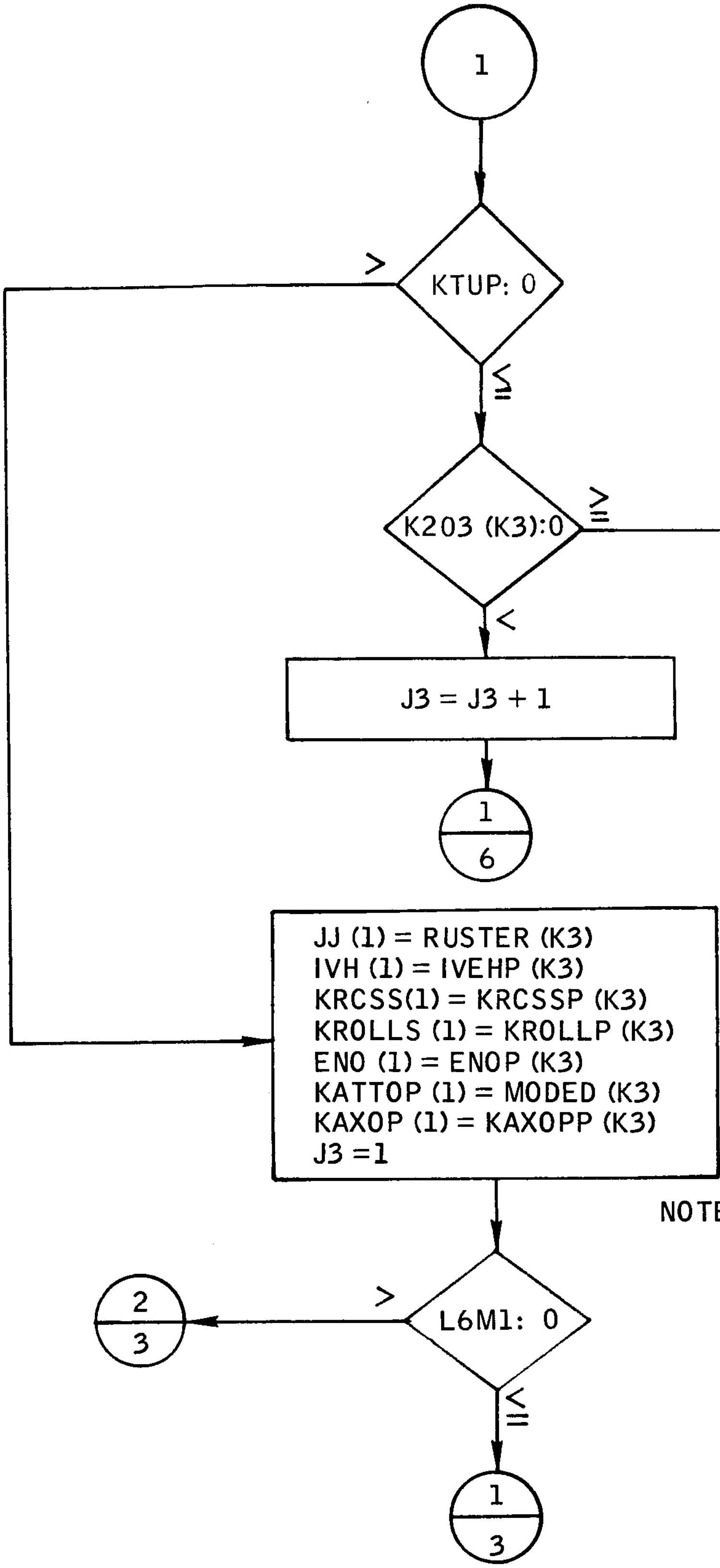
Flow chart .- Detailed flow for MPT1 - Continued.



Flow chart .- Detailed flow for MPT1 - Concluded.



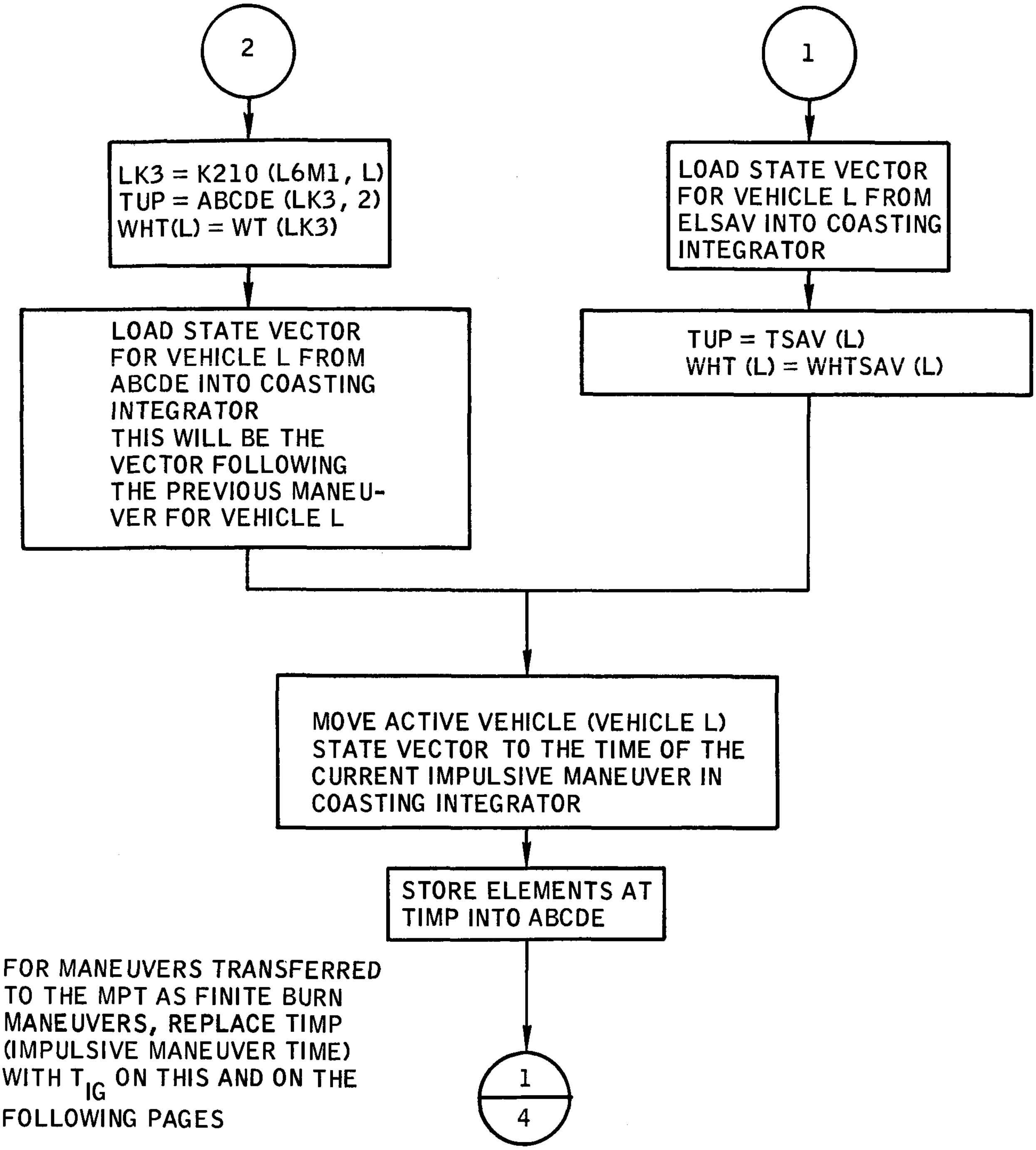
Flow chart .- Detailed flow for MPT2.



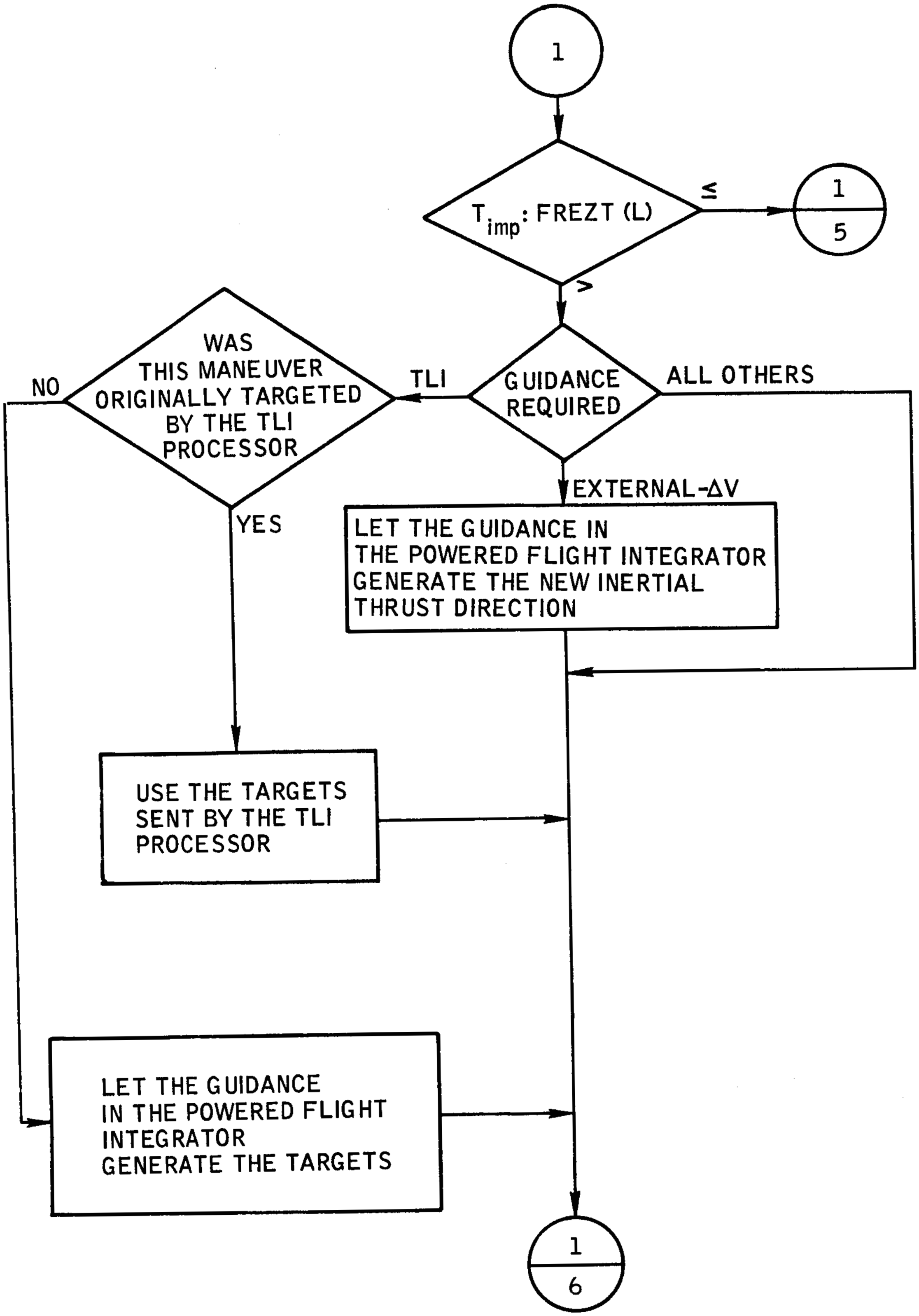
NOTE 1.
ALL VARIABLES WITH A K3 SUBSCRIPT WILL BE FOUND IN THE ABCDE ARRAY

NOTE 2.
CERTAIN OF THESE VARIABLES ARE REQUIRED BY THE INTEGRATOR AND ARE NOT USED BY MPT2 DIRECTLY. THEREFORE THE VARIABLES SET HERE AND THOSE TO BE STORED LATER WILL DEPEND ON THE TRAJECTORY INTEGRATOR USED

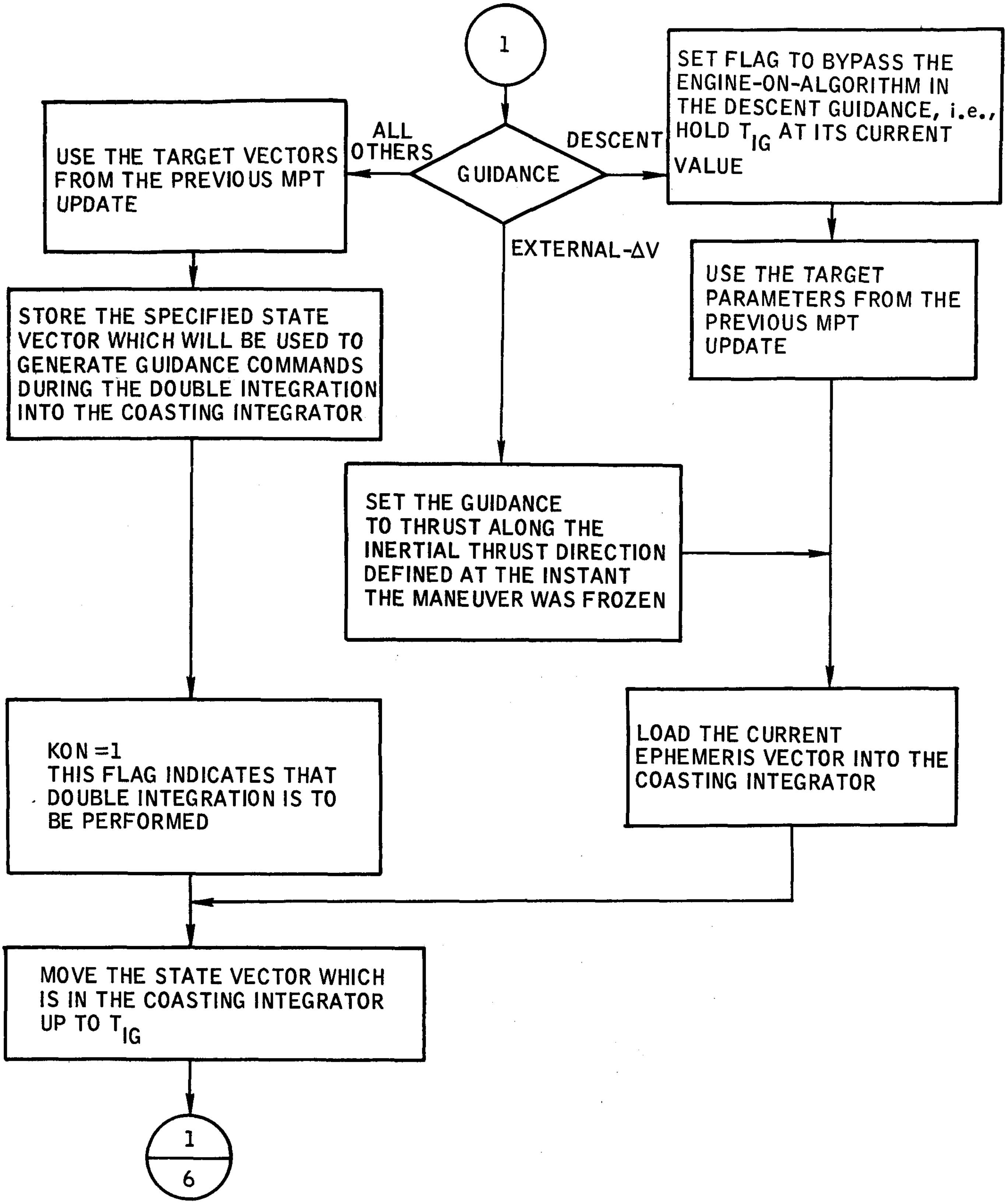
Flow chart .- Detailed flow for MPT2 - Continued.



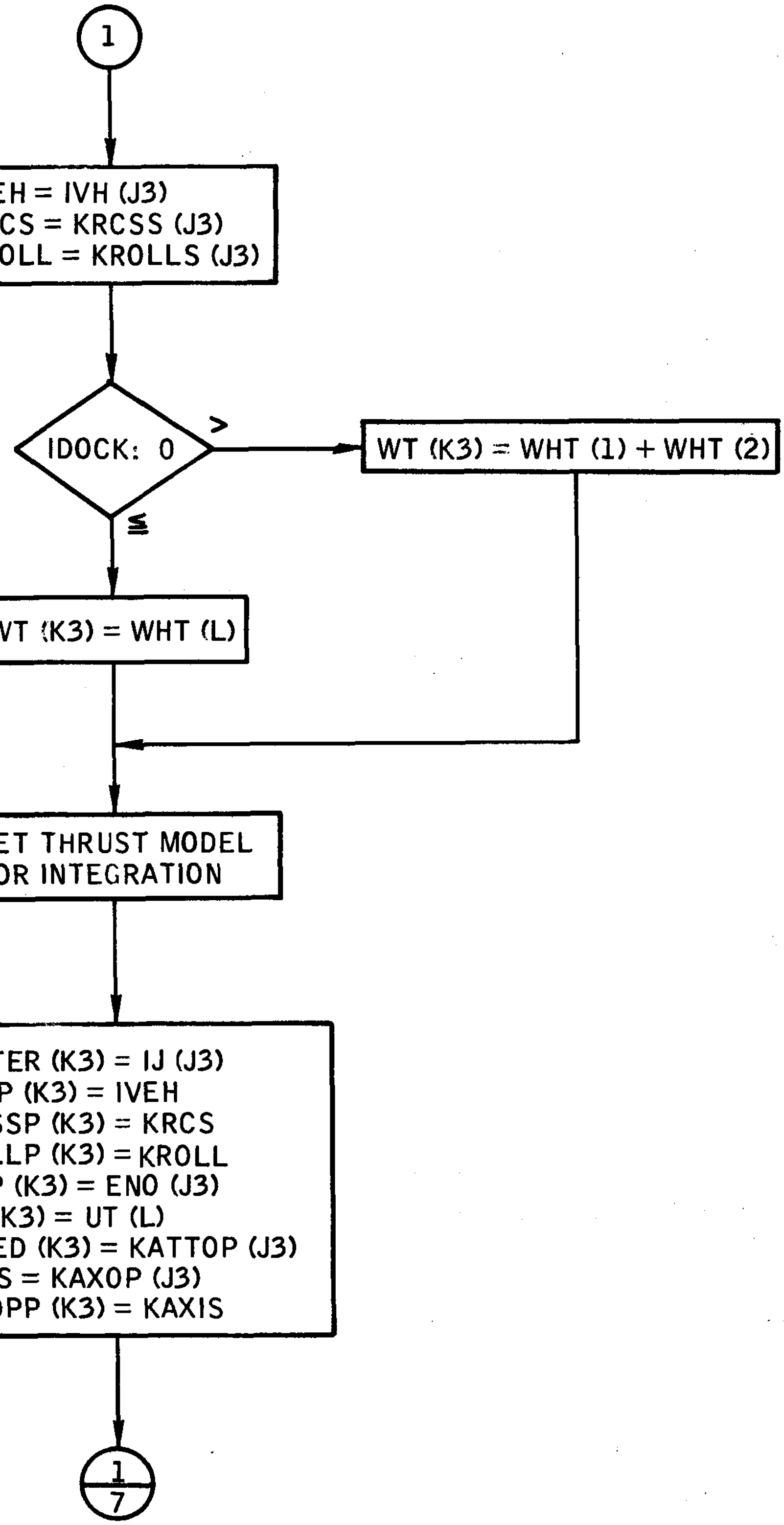
Flow chart .- Detailed flow for MPT2 - Continued.



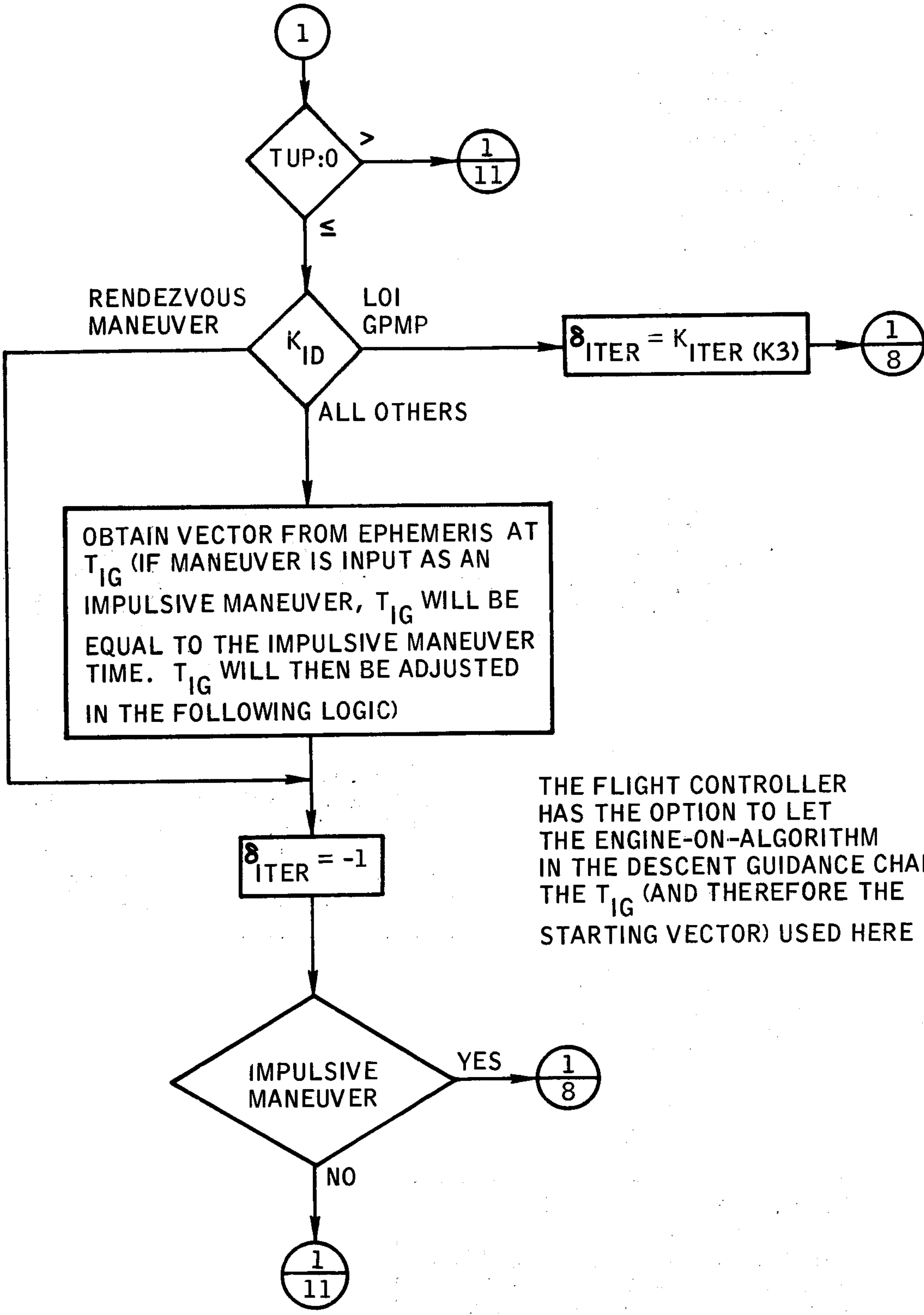
Flow chart .- Detailed flow for MPT2 - Continued.



Flow chart .- Detailed flow for MPT2 - Continued.



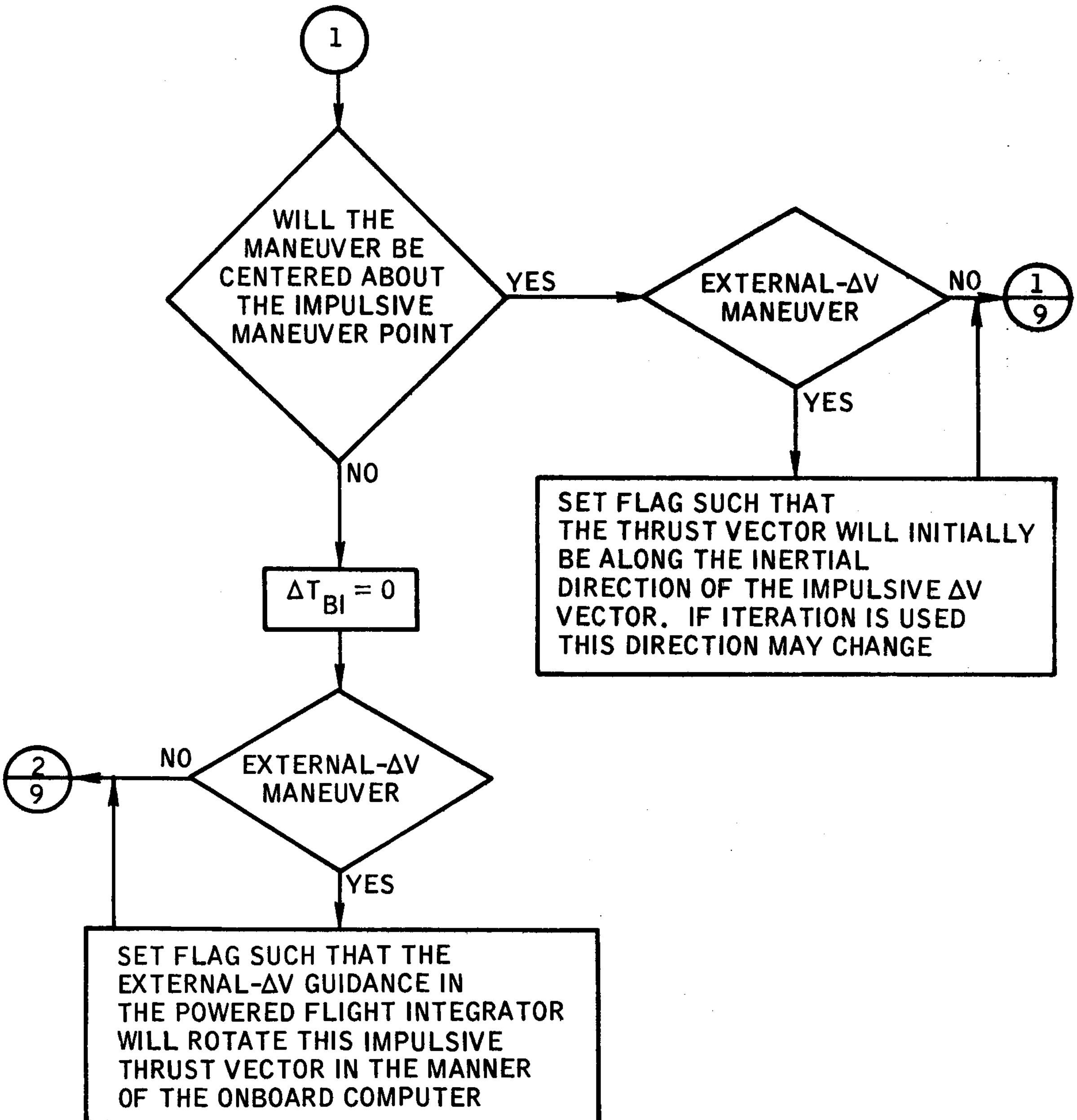
Flow chart .- Detailed flow for MPT2 - Continued.



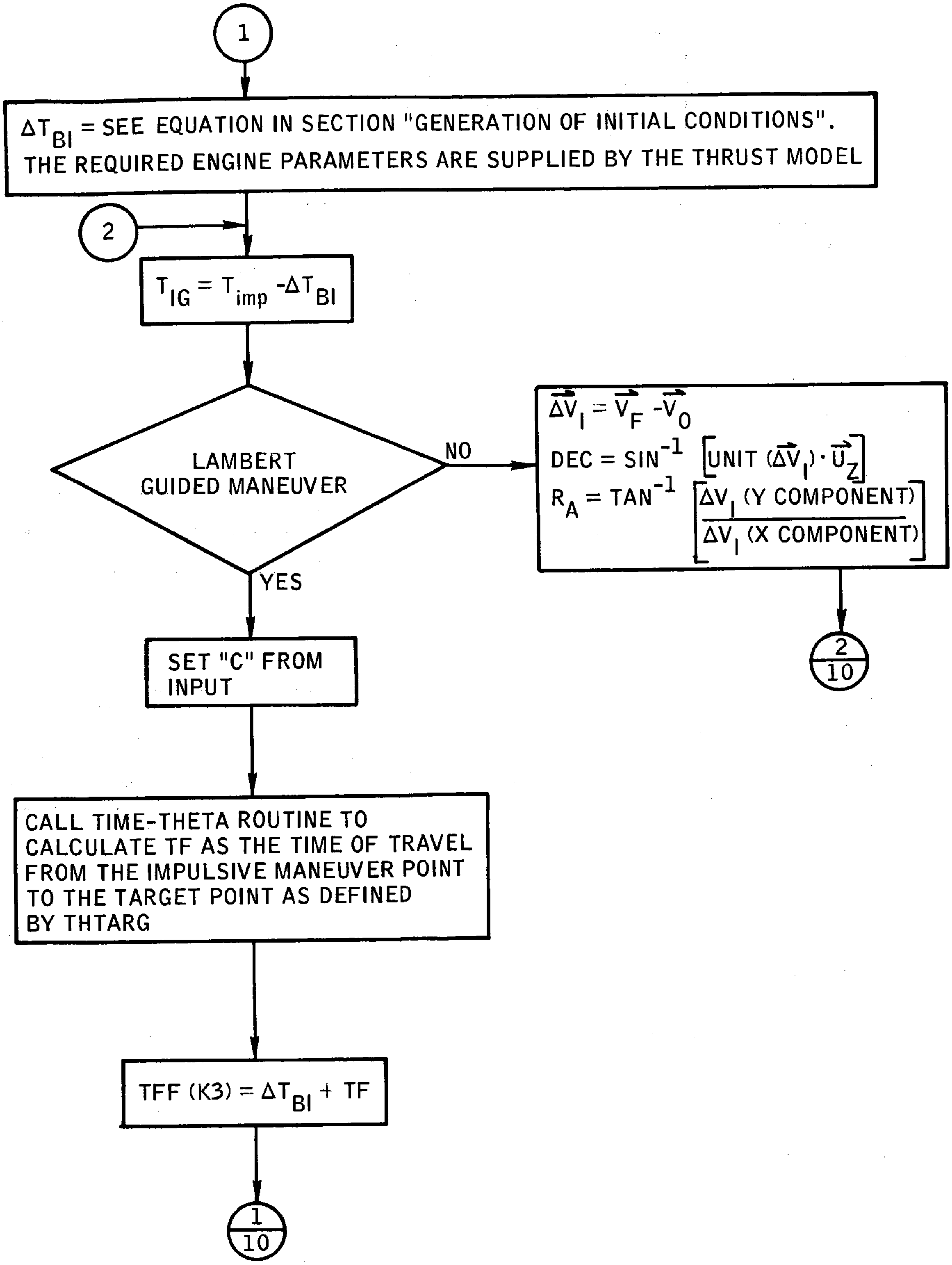
THE FLIGHT CONTROLLER HAS THE OPTION TO LET THE ENGINE-ON-ALGORITHM IN THE DESCENT GUIDANCE CHANGE THE T_{IG} (AND THEREFORE THE STARTING VECTOR) USED HERE

Flow chart .- Detailed flow for MPT2 - Continued.

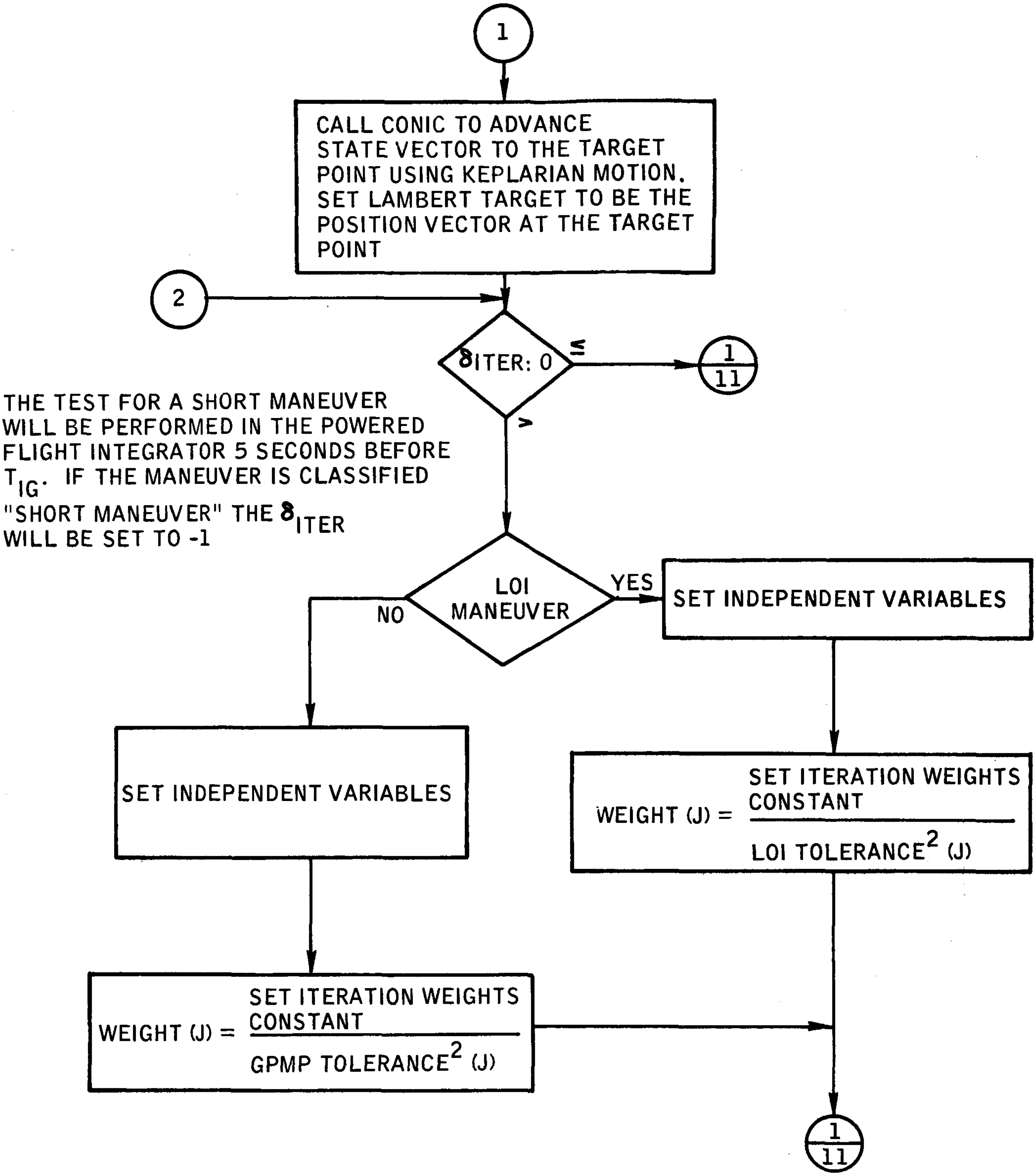
ALL OF THESE MANEUVERS WILL NOMINALLY BE CENTERED ABOUT THE IMPULSIVE MANEUVER POINT EXCEPT FOR LAMBERT GUIDED RENDEZVOUS MANEUVERS WHICH WILL NOMINALLY START AT THE IMPULSIVE MANEUVER POINT. THE FLIGHT CONTROLLER CAN OVERRIDE THE NOMINAL SETTINGS



Flow chart .- Detailed flow for MPT2 - Continued.

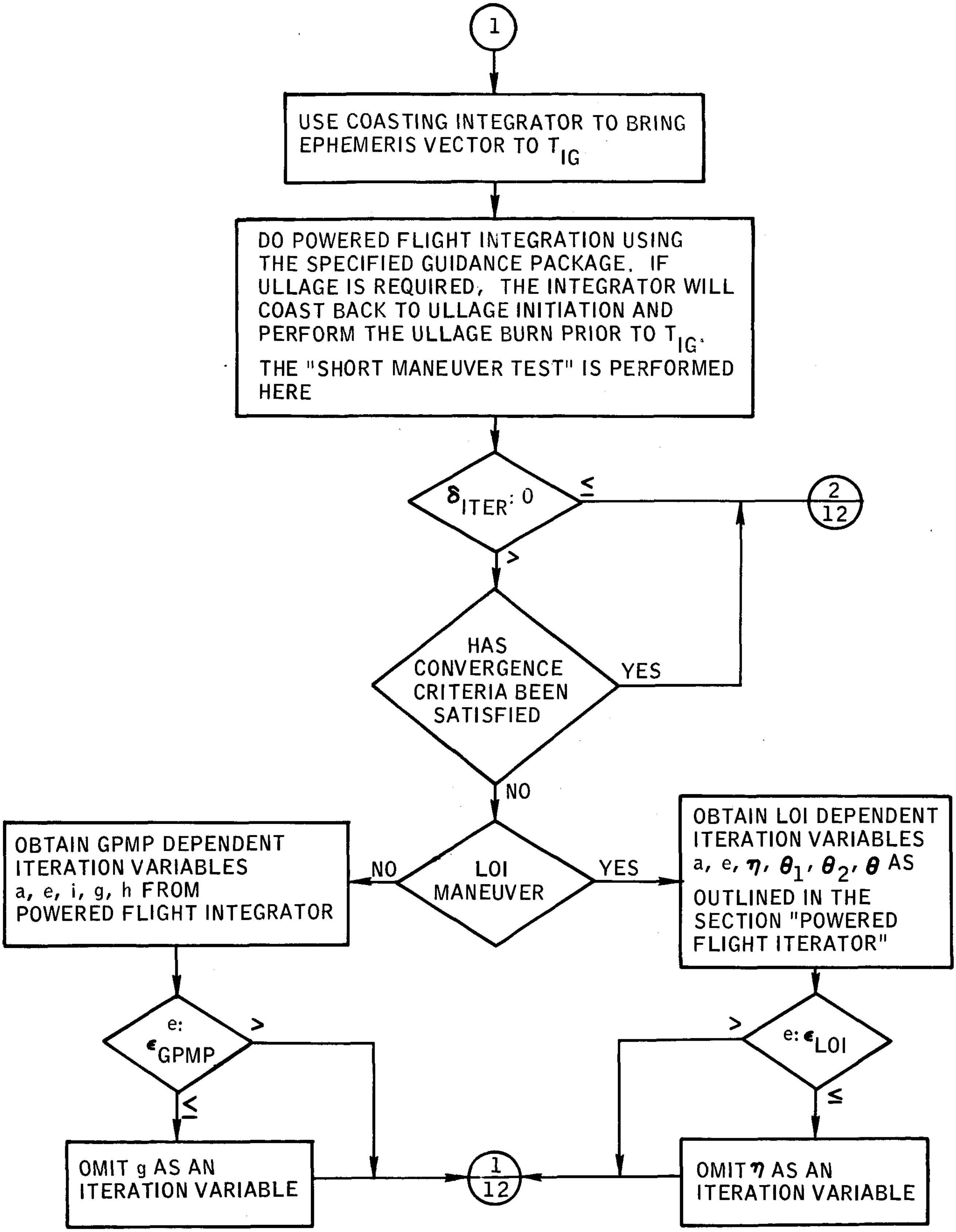


Flow chart .- Detailed flow for MPT2 - Continued.

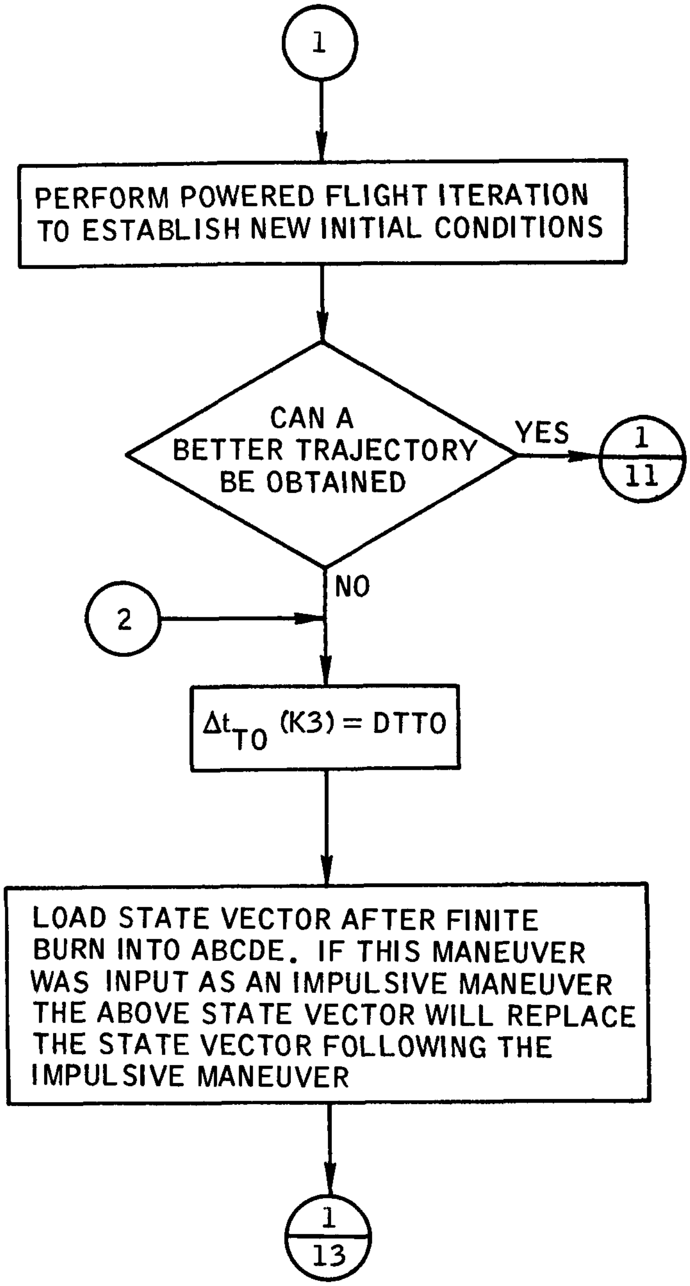


J SUBSCRIPT REPRESENTS THE VARIOUS DEPENDENT VARIABLES

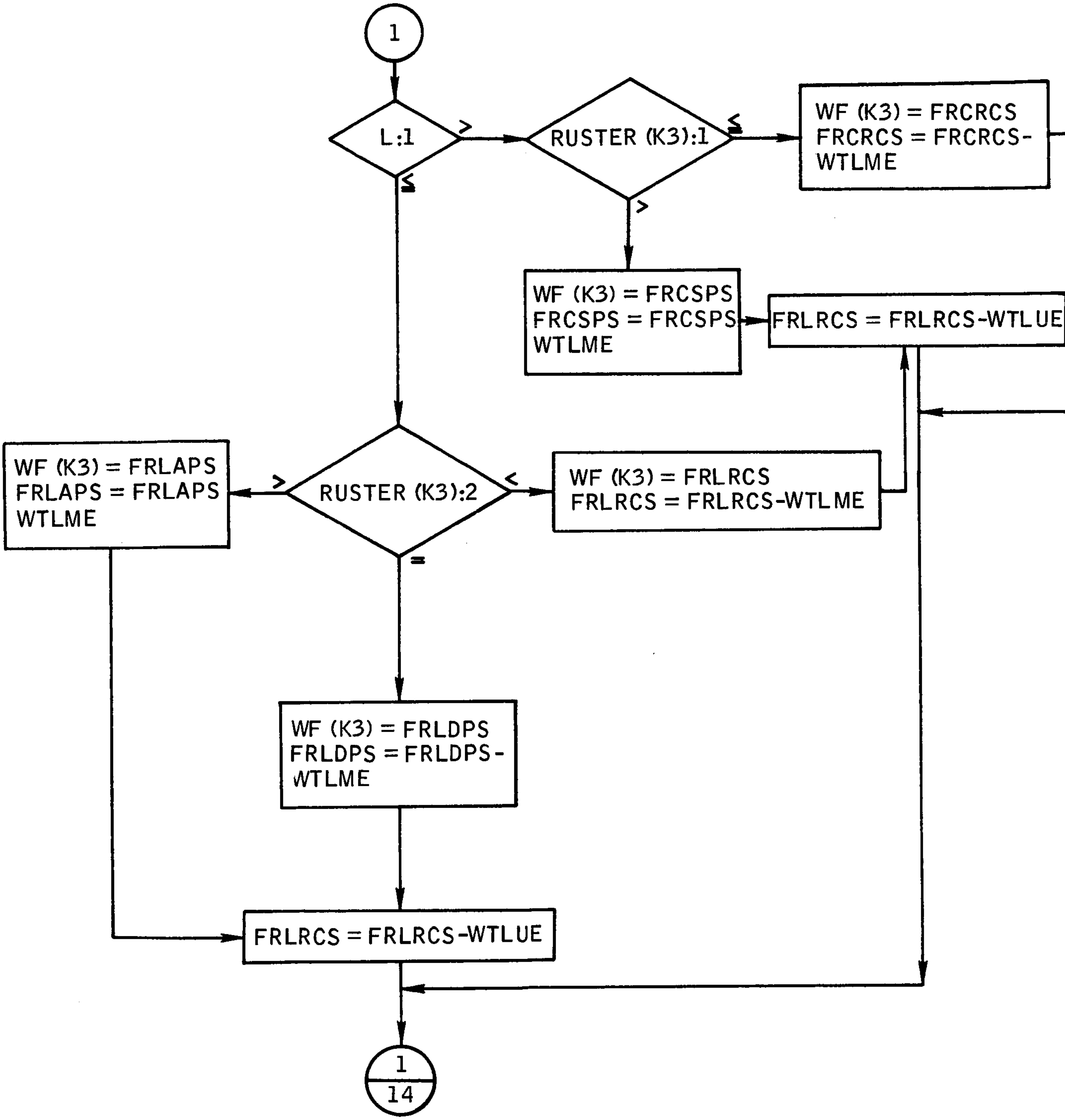
Flow chart .- Detailed flow for MPT2 - Continued.



Flow chart .- Detailed flow for MPT2 - Continued.



Flow chart .- Detailed flow for MPT2 - Continued.



Flow chart .- Detailed flow for MPT2 - Continued.

(1)

THE FOLLOWING PARAMETERS CAN BE TAKEN DIRECTLY FROM THE POWERED FLIGHT INTEGRATOR

PARAMETERS AFTER BURN	PARAMETERS AT T_{IG} BEFORE BURN
WTLME	$\Delta\bar{V}_{GO}$
WTLUE	η_{BI} (K3)
ΔVM (K3)	ϕ_{BI} (K3)
ΔVc (K3)	λ_{BI} (K3)
ΔVwt	α (EXTERNAL-ΔV GUIDANCE ONLY)
Δt_B (K3)	$\bar{R}_{BI}$
YD (K3) (ASCENT GUIDANCE ONLY)	T_{IG}
$\bar{R}$co	LVLH
$\bar{V}$co	$\overline{AT}_{BI}$
a (K3)	$\overline{\Delta VI}'$
e (K3)	TUI
i (K3)	$\bar{R}_{ul}$
ωp (K3)	
u (L)	

$\text{SIN}\,\phi = R_{BI}\,(3)/\,|R_{BI}|$

WHT (L) = WHT (L) - WTLME-WTLUE

$$h_{BI} = |\bar{R}_{BI}| - \frac{R_e}{\sqrt{1 + \text{SIN}^2\phi\left[\left(\frac{Re}{Rp}\right)^2 - 1\right]}}$$

GETI (K3) = T_{IG}

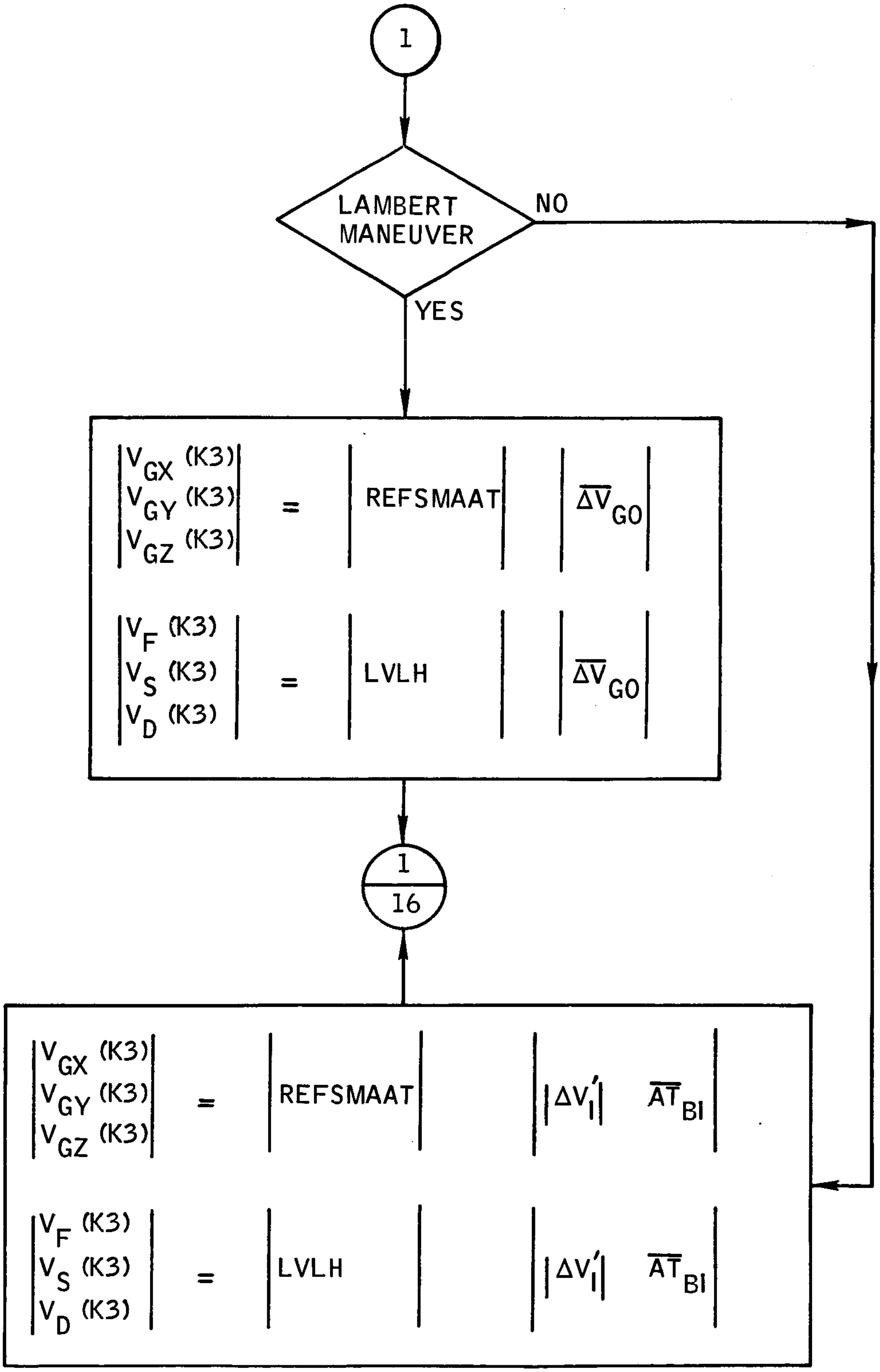
GETCO (K3) = GETI (K3) + Δt_B (K3)

ΔV_{TO} (K3) = ΔV_m (K3) - ΔV_{WT}

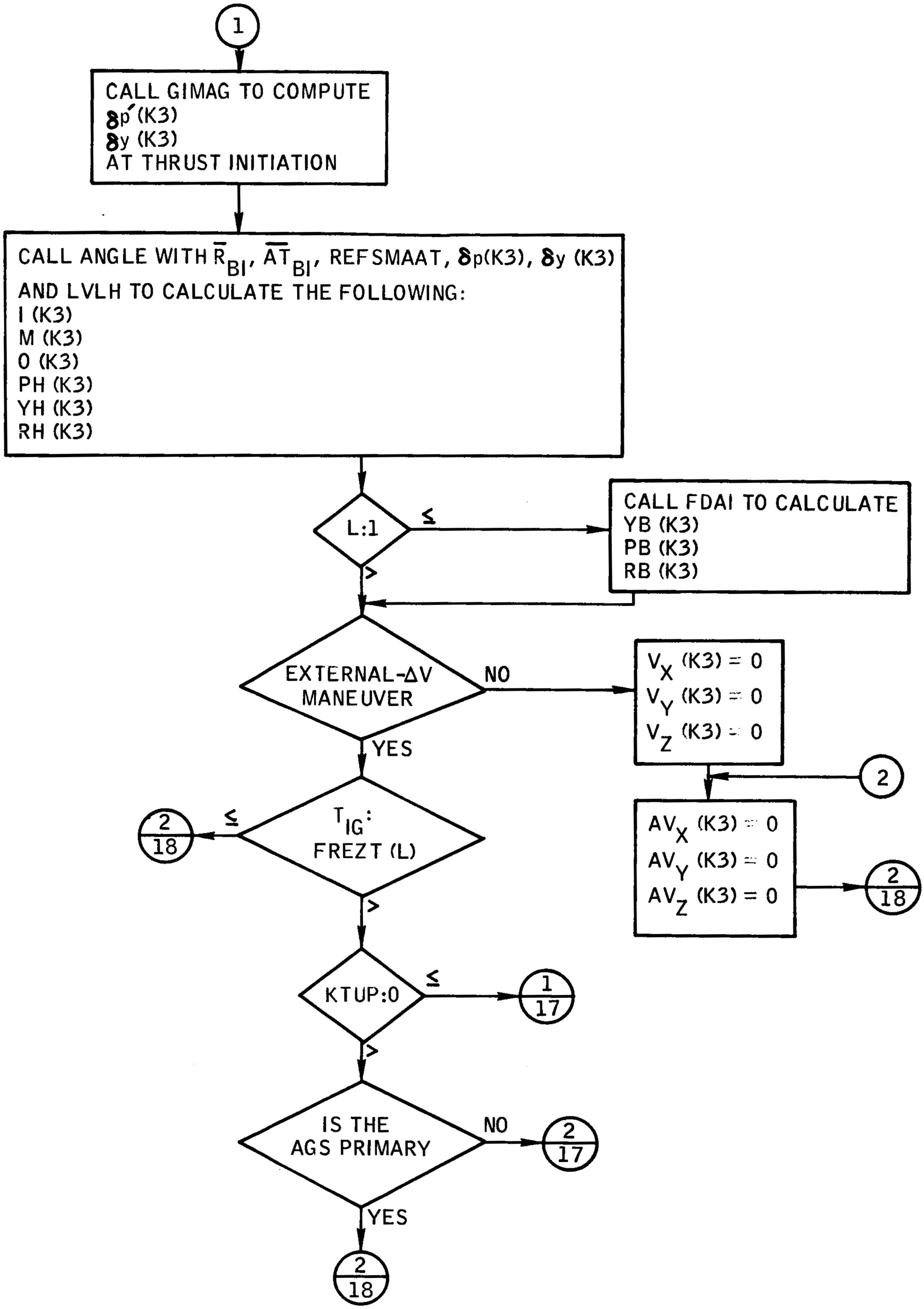
$|\bar{R}_{BI}|$ INDICATES THE MAGNITUDE OF $\bar{R}_{BI}$. R_{BI} (3) INDICATES THE Z COMPONENT OF $\bar{R}_{BI}$

$\frac{1}{15}$

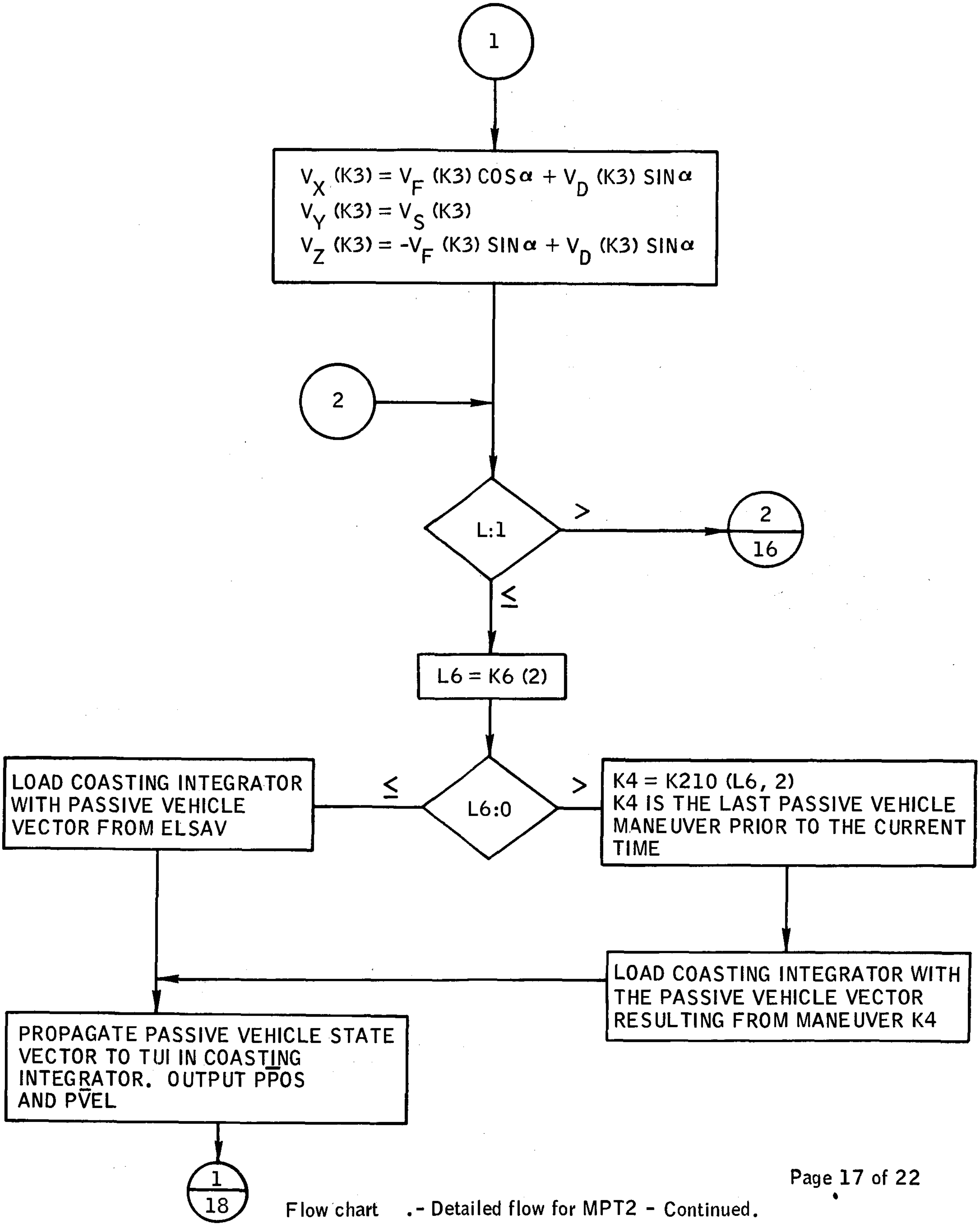
Flow chart .- Detailed flow for MPT2 - Continued.



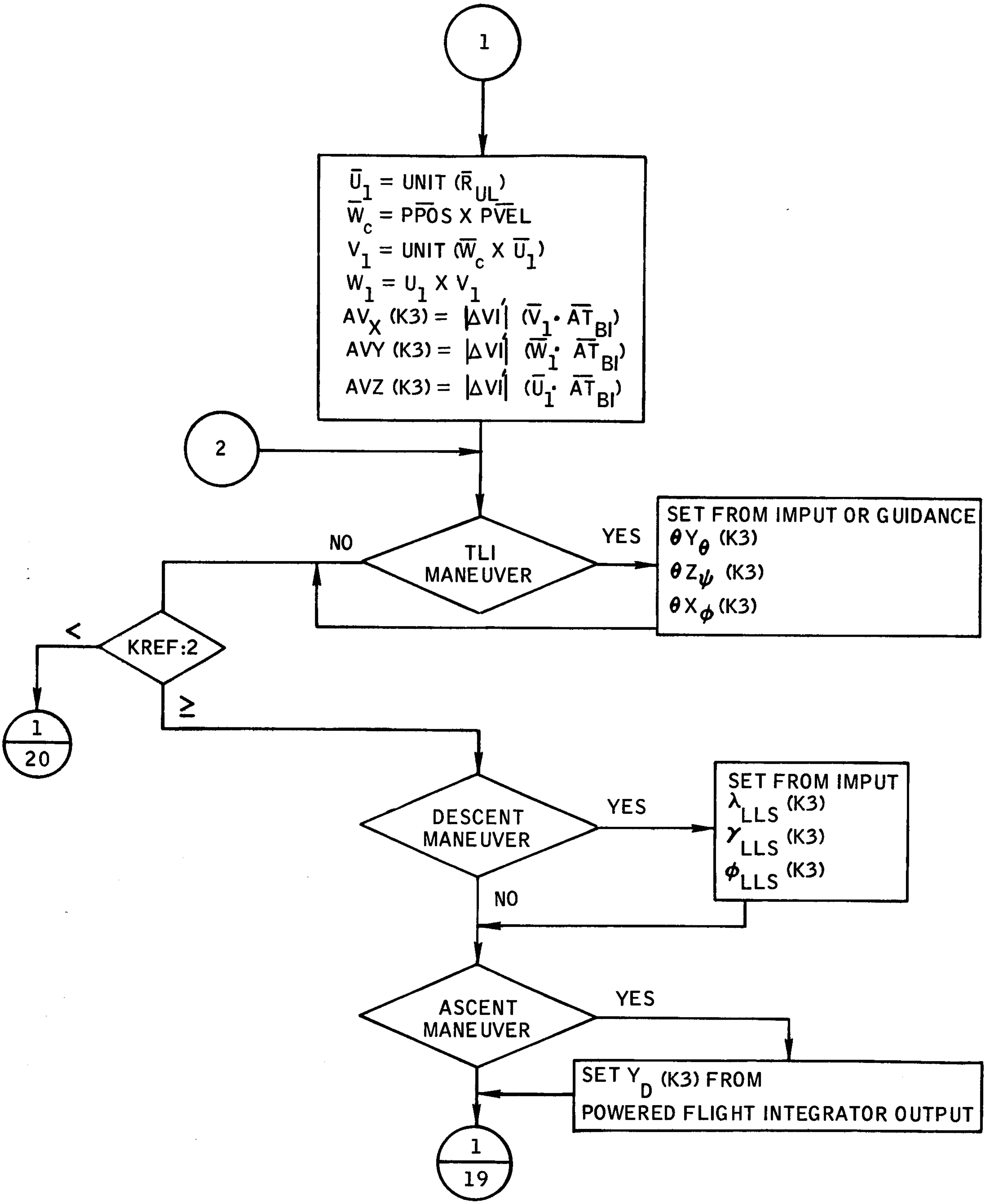
Flow chart .- Detailed flow for MPT2 - Continued.



Flow chart .- Detailed flow for MPT2 - Continued.



Flow chart .- Detailed flow for MPT2 - Continued.



Flow chart .- Detailed flow for MPT2 - Continued.

1

CALL LNDSIT TO LOCATE LANDING SITE ($\bar{R}_{LS}$) AT GETCO (K3)

SUBSCRIPT 3 DENOTES THE Z COMPONENT

$$\bar{H}_{CO} = \text{UNIT}\,(\bar{R}_{CO} \times \bar{V}_{CO})$$

$$\bar{V}_{LS} = \bar{H}_{CO} \times \bar{R}_{LS}$$

$$\bar{H}' = \text{UNIT}(\bar{R}_{LS} \times \bar{V}_{LS})$$

$$\delta_P{}^{*} = \left(\frac{H_{CO}(3) - H'(3)}{\left|H_{CO}(3) - H'(3)\right|}\right) \cos^{-1}\left[\bar{H}_{CO} \cdot \bar{H}'\right]$$

CALL STAP TO MOVE THE ACTIVE VEHICLE'S STATE VECTOR TO THE NEXT PERICYNTHION FOLLOWING THE MANEUVER. STAP UTILIZES THE COASTING INTEGRATOR

V_P (K3) = VELOCITY MAGNITUDE IN THE COASTING INTEGRATOR

CALL LNDSIT TO LOCATE $\bar{R}_{LS}$ AT TIME OF PERICYNTHION

$$\theta_P = \cos^{-1}\left[\text{UNIT}\,(\bar{R}_{LS}) \cdot \text{UNIT}\,(\bar{R}_P)\right]$$

$\bar{R}_P$ IS THE RADIUS VECTOR AT PERICYNTHION FOUND BY STAP

2
20

Flow chart .- Detailed flow for MPT2 - Continued.

1

CALL STAP TO FIND STATE VECTOR FOR VEHICLE L AT FIRST PERIGEE FOLLOWING MANEUVER

HERE R(L) IS THE RADIUS AT PERIGEE

$$h_p\,(K3) = \frac{R(L) - R_{REF}}{AMILE}$$

2

KL = 3 - L
L6 = K6 (KL)
K4 = K210 (L6, KL)

PROPAGATE THE PASSIVE VEHICLE'S STATE VECTOR FOLLOWING THE K4 MANEUVER TO GETCO (K3)
OUTPUT: $\overline{PPOS}$, $\overline{PVEL}$

USE THETR TO CALCULATE θ (K3)

SUBSCRIPT 3 DENOTES THE Z COMPONENT

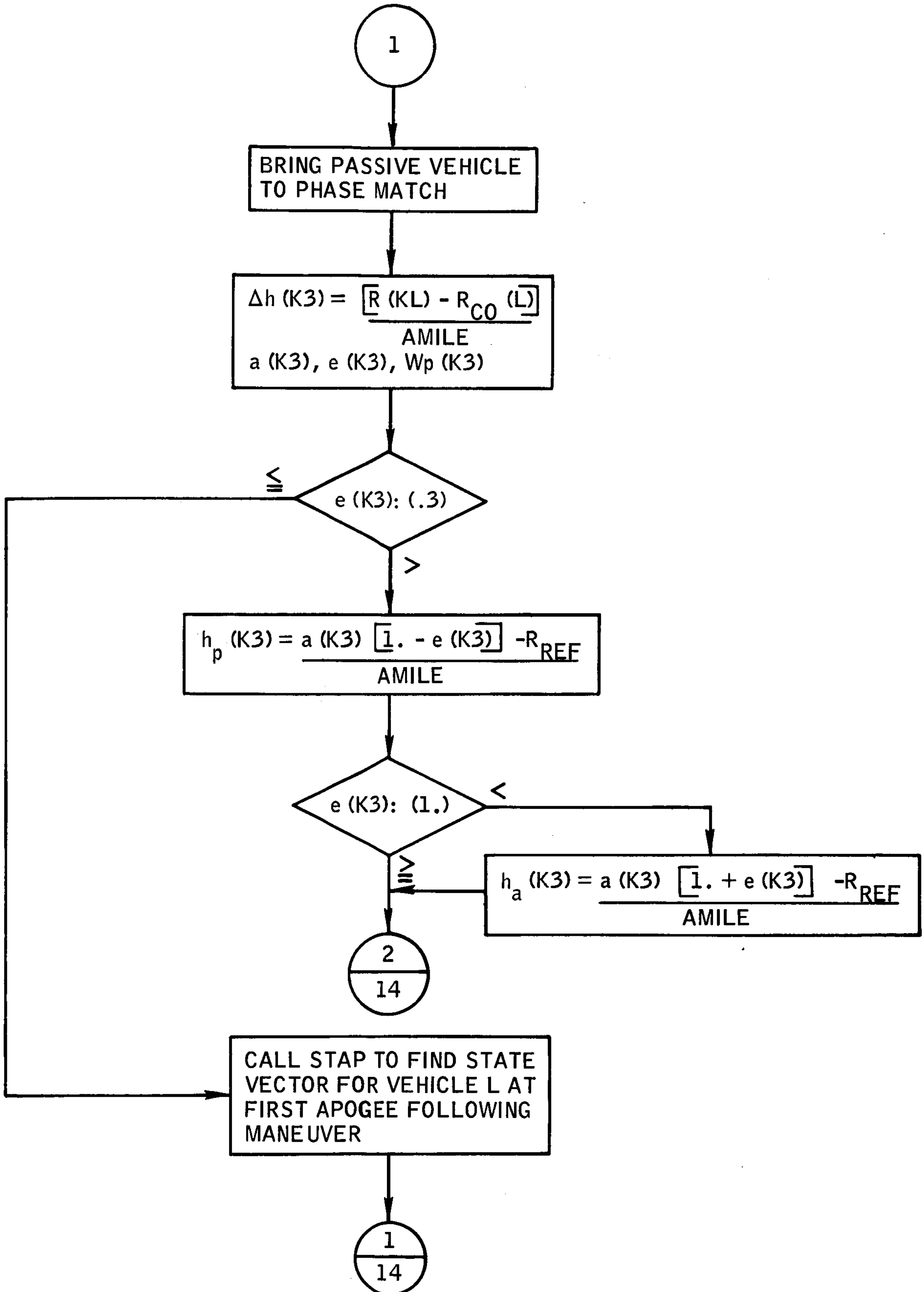
$$\dot{\theta}(K3) = 2\pi \left[1 - NT/NC\right]$$

$$\overline{HPAS} = UNIT\,(\overline{PPOS} \times \overline{PVEL})$$

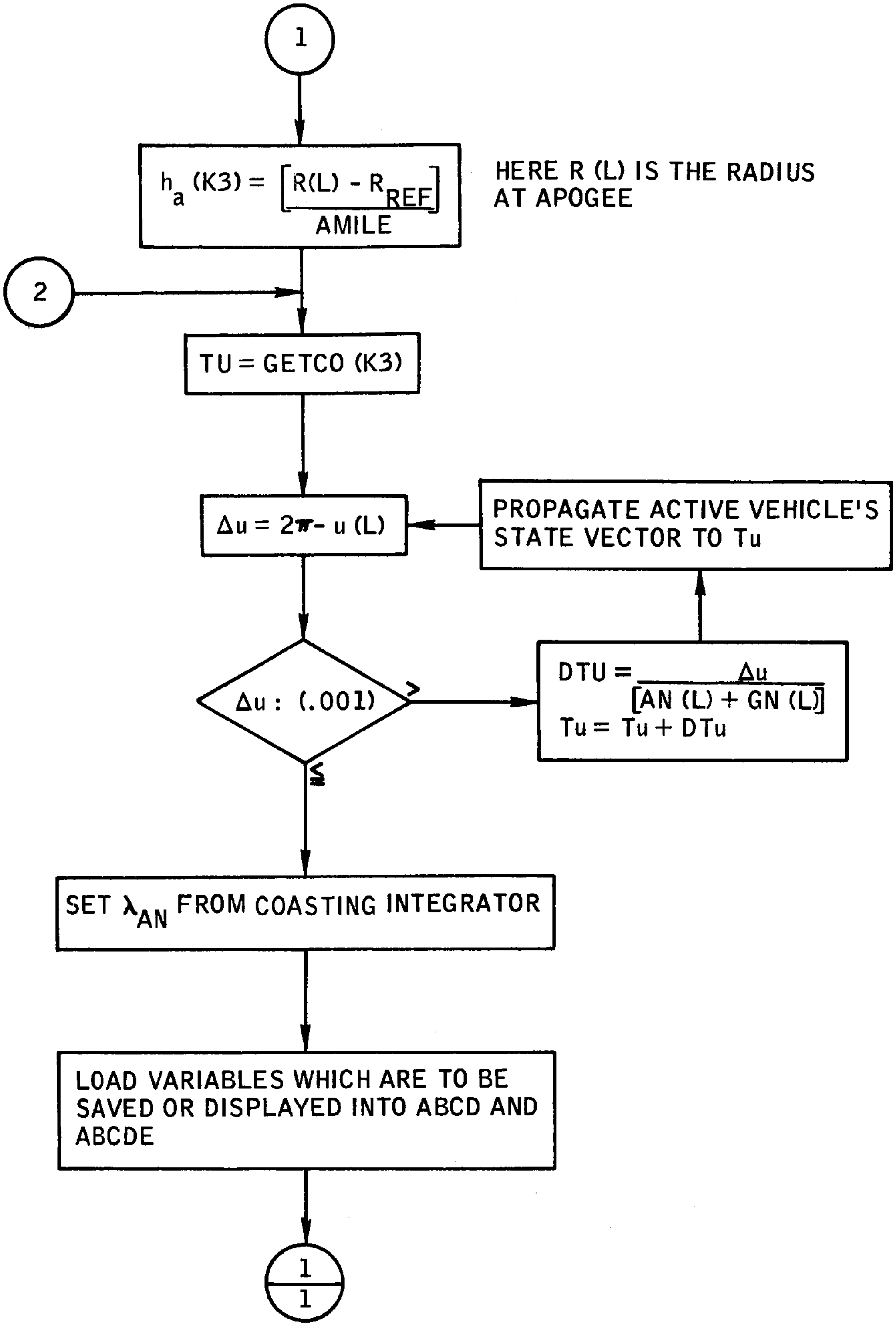
$$\delta\,(K3) = \frac{HPAS\,(3) - H_{CO}\,(3)}{\left|HPAS\,(3) - H_{CO}\,(3)\right|}\left[\cos^{-1}\,(\overline{HPAS} \cdot \overline{H}_{CO})\right]$$

1
21

Flow chart .- Detailed flow for MPT2 - Continued.



Flow chart .- Detailed flow for MPT2 - Continued.



Flow chart .- Detailed flow for MPT2 - Concluded.